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Koyama et al.

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(45) **Date of Patent: Sep. 28, 2004**

(54) **SHEET THICKNESS DETECTING METHOD AND DEVICE THEREFOR IN BENDING MACHINE, REFERENCE INTER-BLADE DISTANCE DETECTING METHOD AND DEVICE THEREFOR, AND BENDING METHOD AND BENDING DEVICE**

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(73) Assignee: **Amada Company, Limited**, Kanagawa (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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PCT Pub. Date: **Jul. 26, 2001**

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US 2003/0000268 A1 Jan. 2, 2003

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Jan. 21, 2000	(JP)	2000-012771
Jan. 21, 2000	(JP)	2000-013050
Jan. 27, 2000	(JP)	2000-19248

(51) **Int. Cl.**[7] **B21C 51/00**
(52) **U.S. Cl.** **72/31.11**; 72/20.1; 72/20.2; 72/389.3
(58) **Field of Search** 72/373, 375, 379.2, 72/20.1, 20.2, 21.1, 21.4, 31.1, 31.11, 389.1, 389.3, 702

(56) **References Cited**

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JP	5-171339	* 1/1995	.... B21D/5/02
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English Language Abstract of JP 6–74746.

English Language Abstract of JP 63–157722.

English Language Abstract of JP 8–15624.

* cited by examiner

Primary Examiner—Ed Tolan
(74) *Attorney, Agent, or Firm*—Greenblum & Bernstein, P.L.C.

(57) **ABSTRACT**

A plate thickness detector for a bending machine causes a punch to make a relative stroke and bend a workpiece mounted on an upper surface of a die cooperatively by the punch and the die. A displacement gauge is provided in the die, is always urged upward from a V-groove of the die, and measures a distance from the upper surface of the die to a lower surface of the workpiece. A ram position detector detects a relative stroke quantity of the punch to the die. The punch is caused to bend the workpiece from a position away from the die by a reference inter-blade distance. A plate thickness arithmetic operation section inputs the relative stroke quantity of the punch at a point at which descent of the workpiece is detected by the displacement gauge or a predetermined point after the point, inputs the displacement quantity of the displacement gauge at this time using ram position detector, and detects the plate thickness of the workpiece by subtracting the detected relative stroke quantity from the reference inter-blade distance and adding the displacement quantity detected by the displacement gauge to the subtraction result.

8 Claims, 23 Drawing Sheets

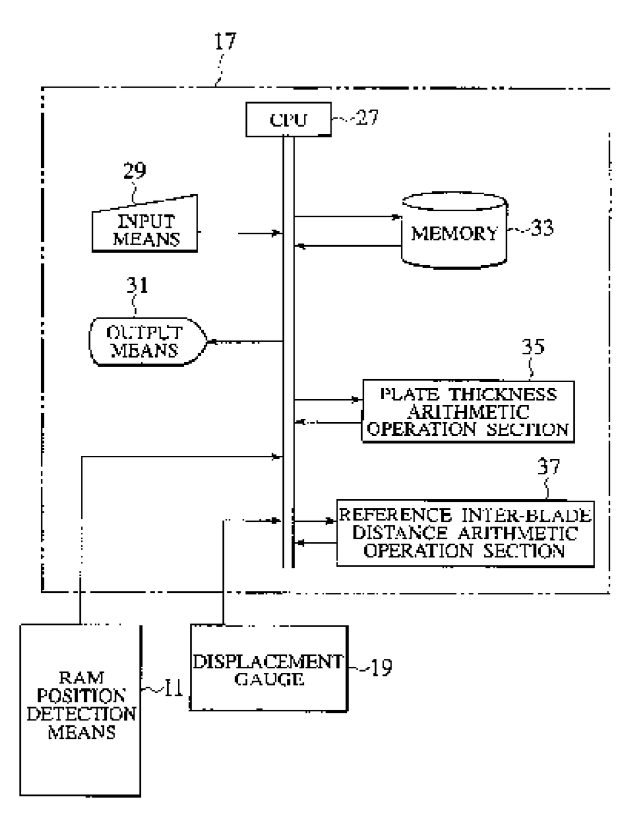


FIG. 1
PRIOR ART

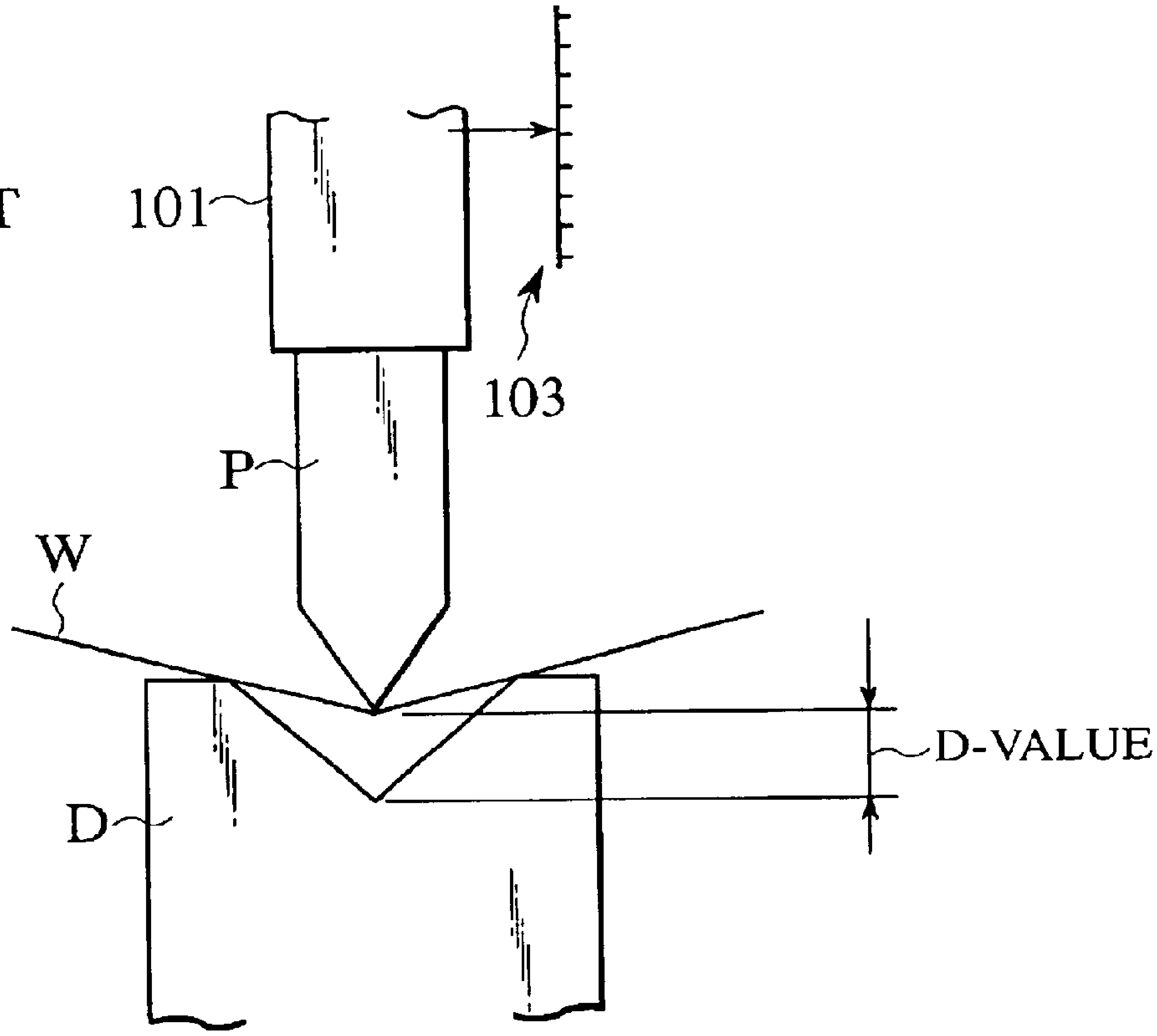


FIG. 2
PRIOR ART

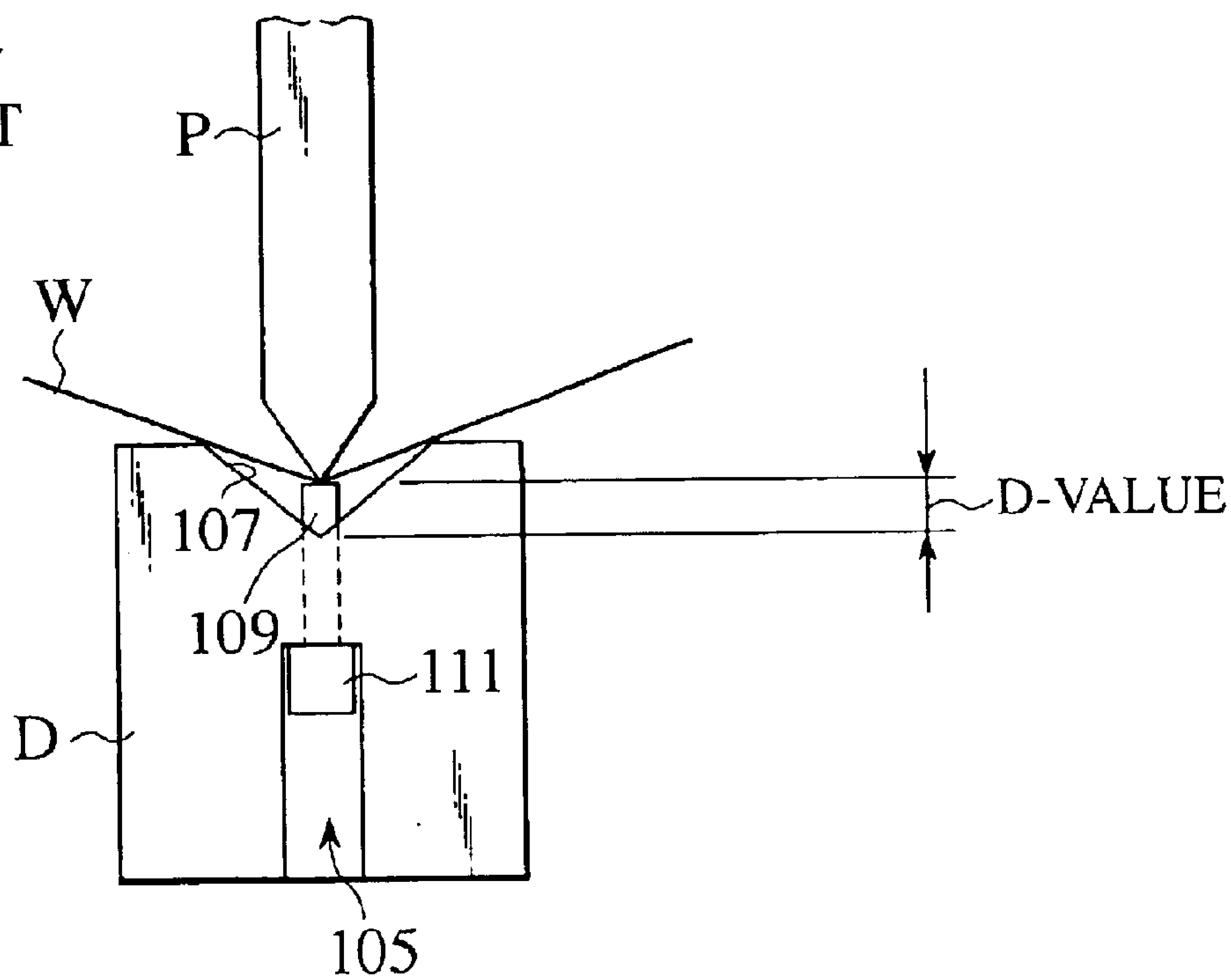


FIG. 3

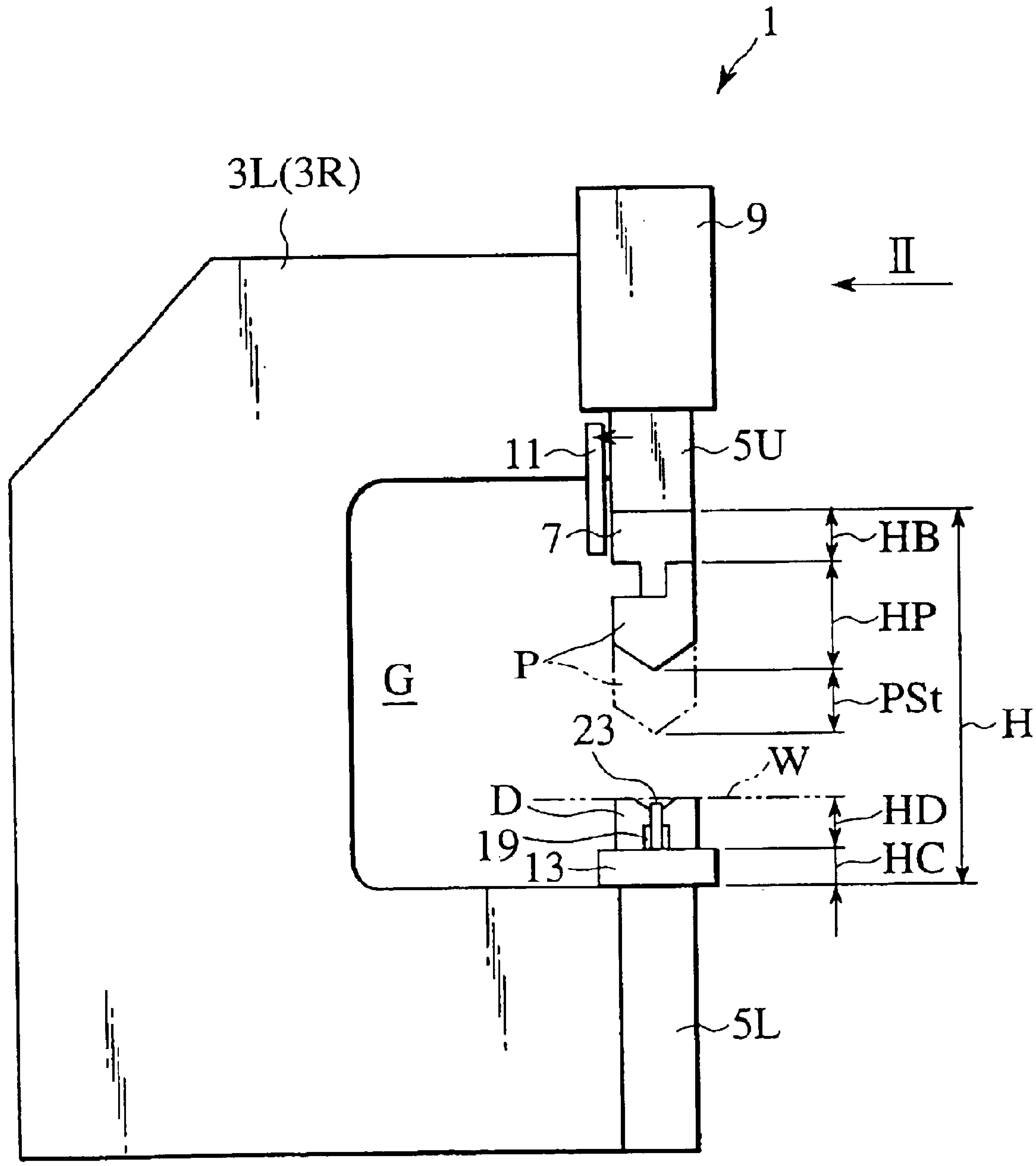


FIG. 4

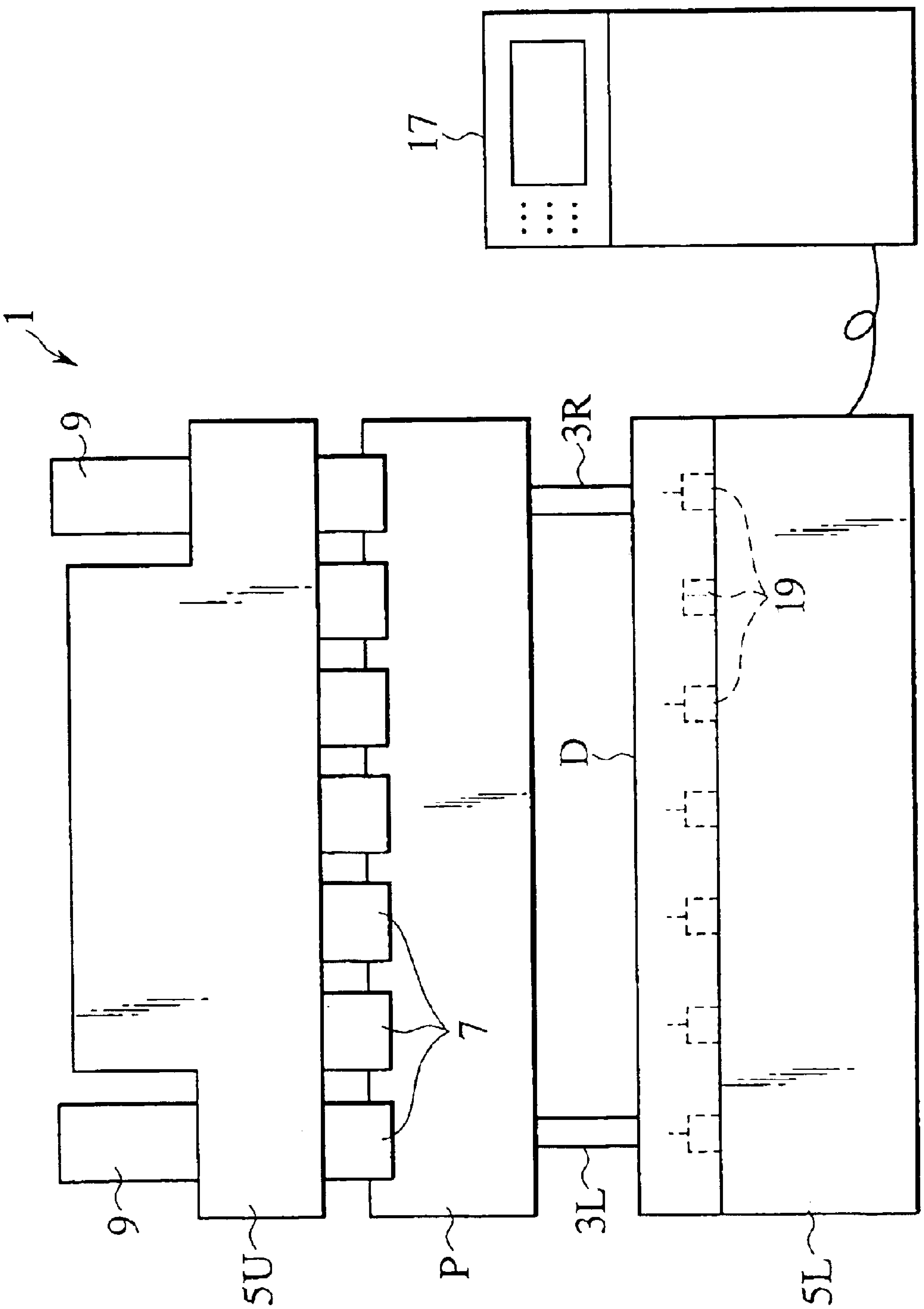


FIG. 5

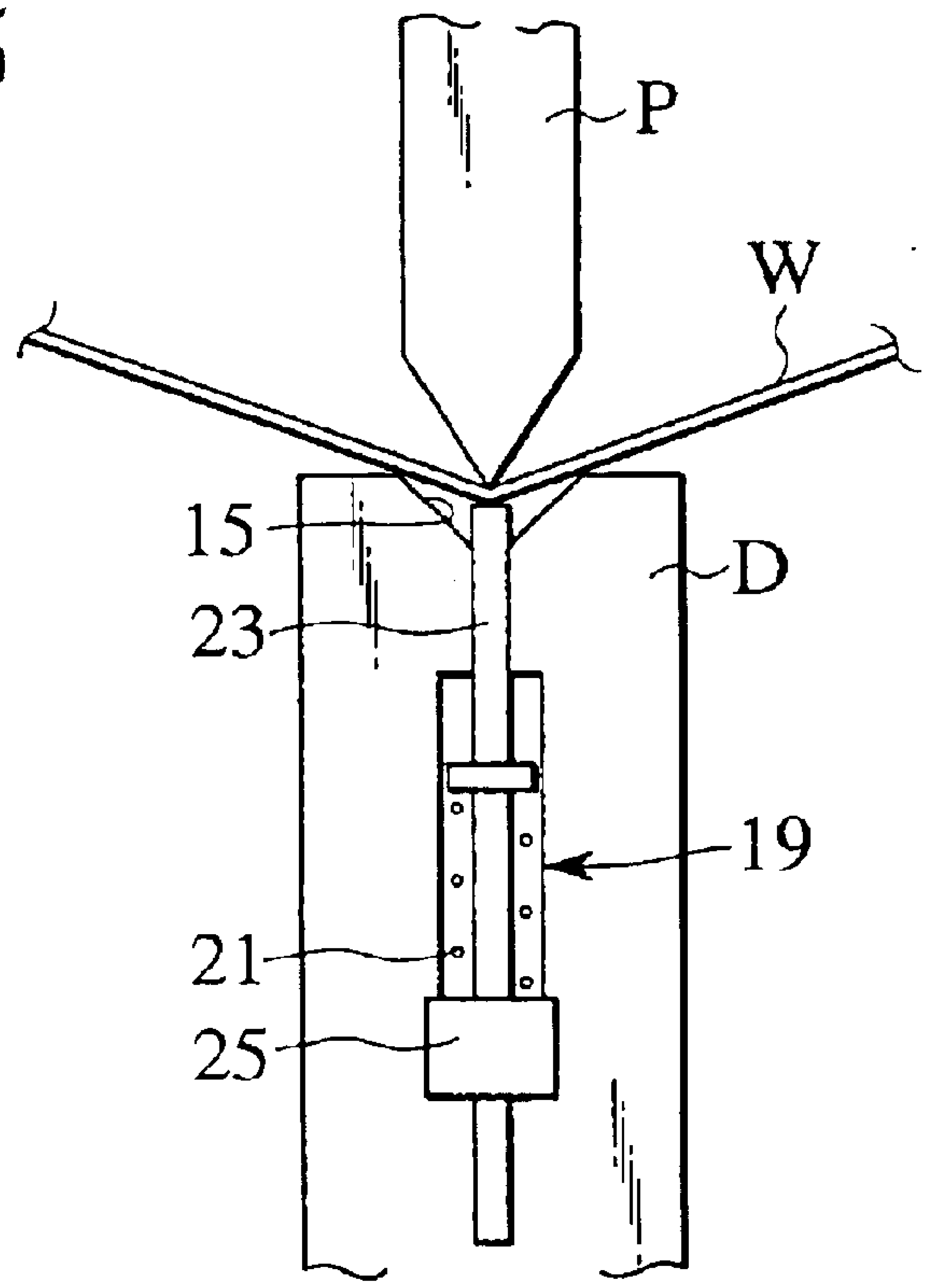


FIG. 6

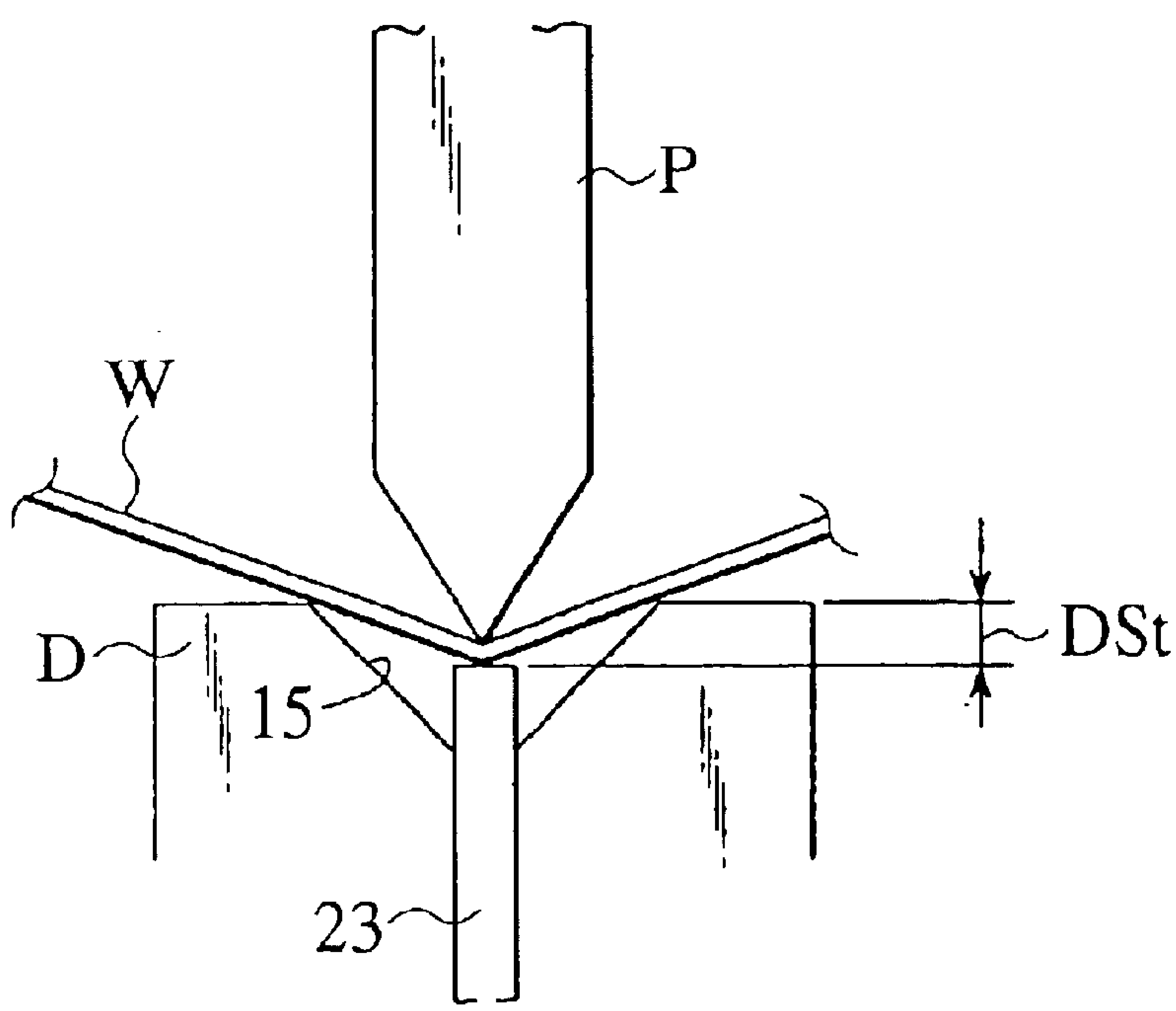


FIG. 7

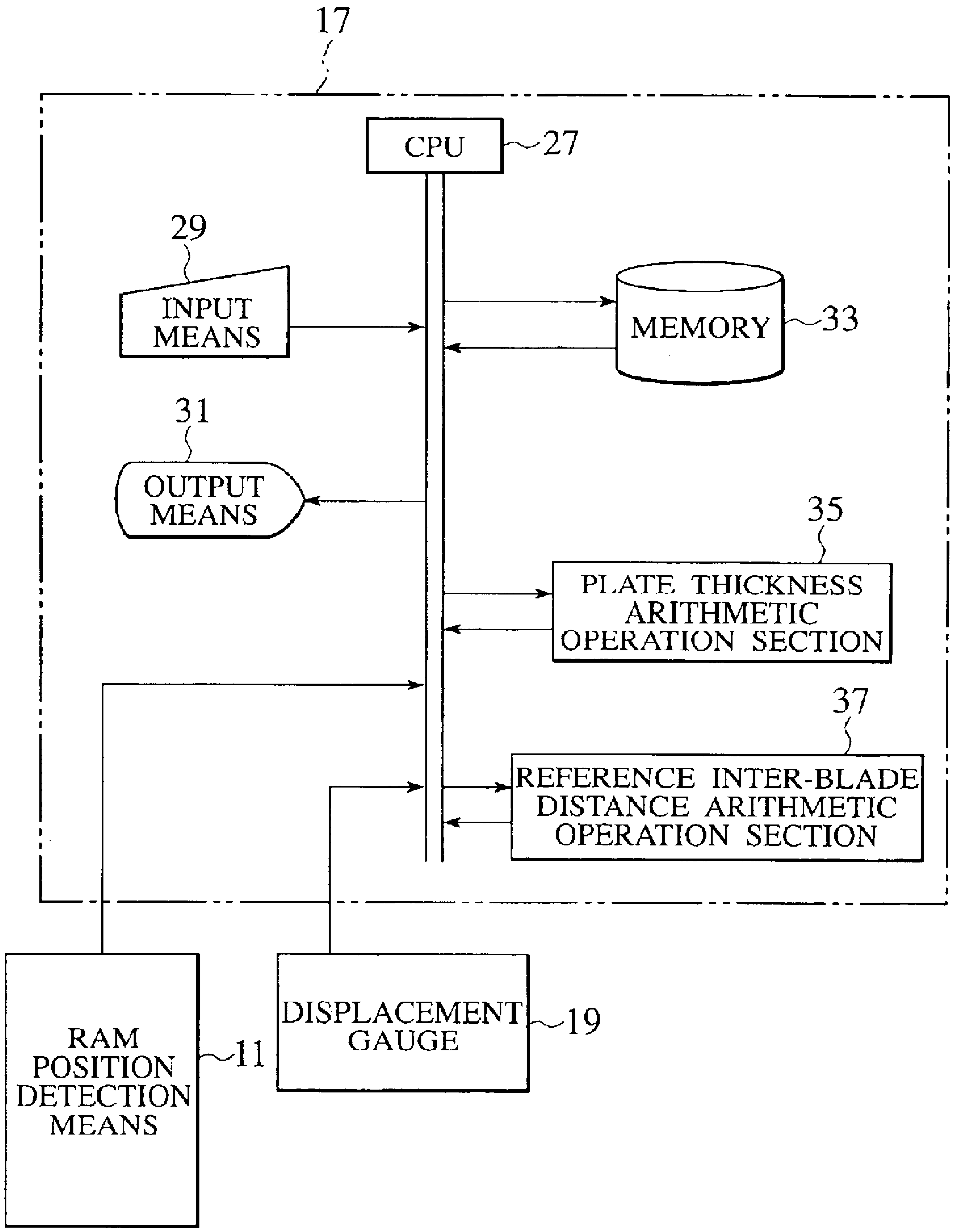

17
CPU
27
29
INPUT MEANS
MEMORY
33
31
OUTPUT MEANS
35
PLATE THICKNESS ARITHMETIC OPERATION SECTION
37
REFERENCE INTER-BLADE DISTANCE ARITHMETIC OPERATION SECTION
RAM POSITION DETECTION MEANS
11
DISPLACEMENT GAUGE
19

FIG. 8

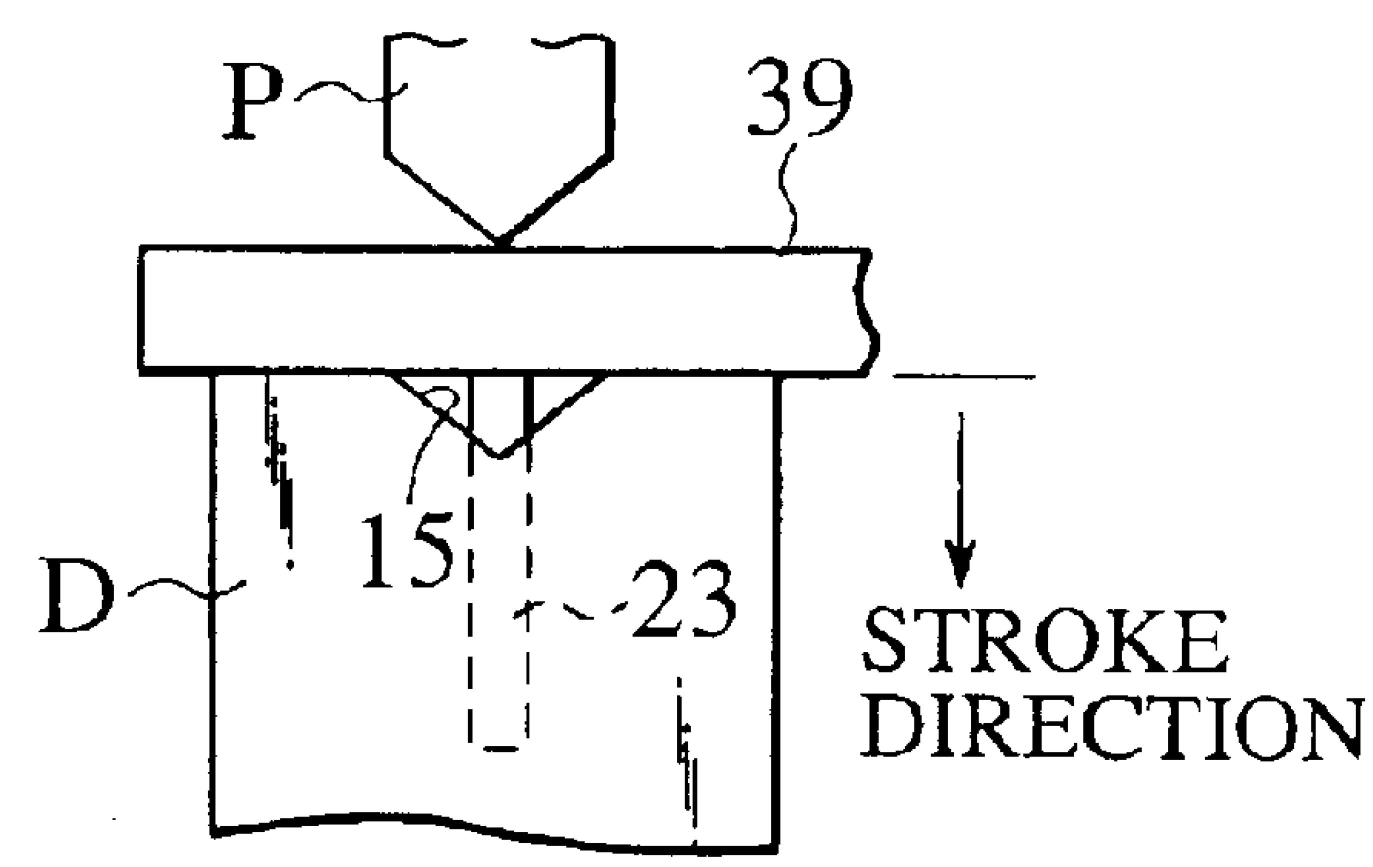


FIG. 9

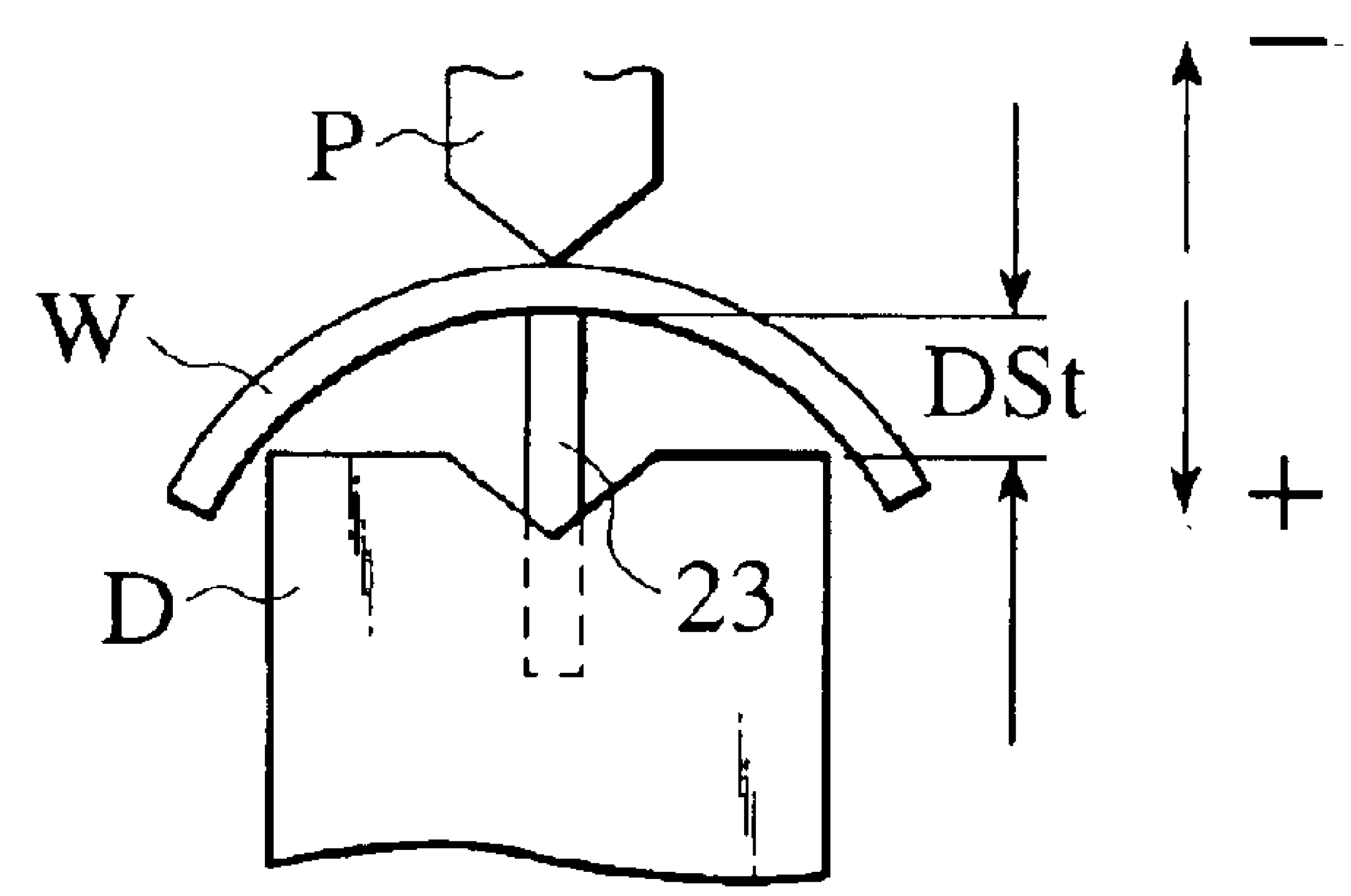


FIG. 10

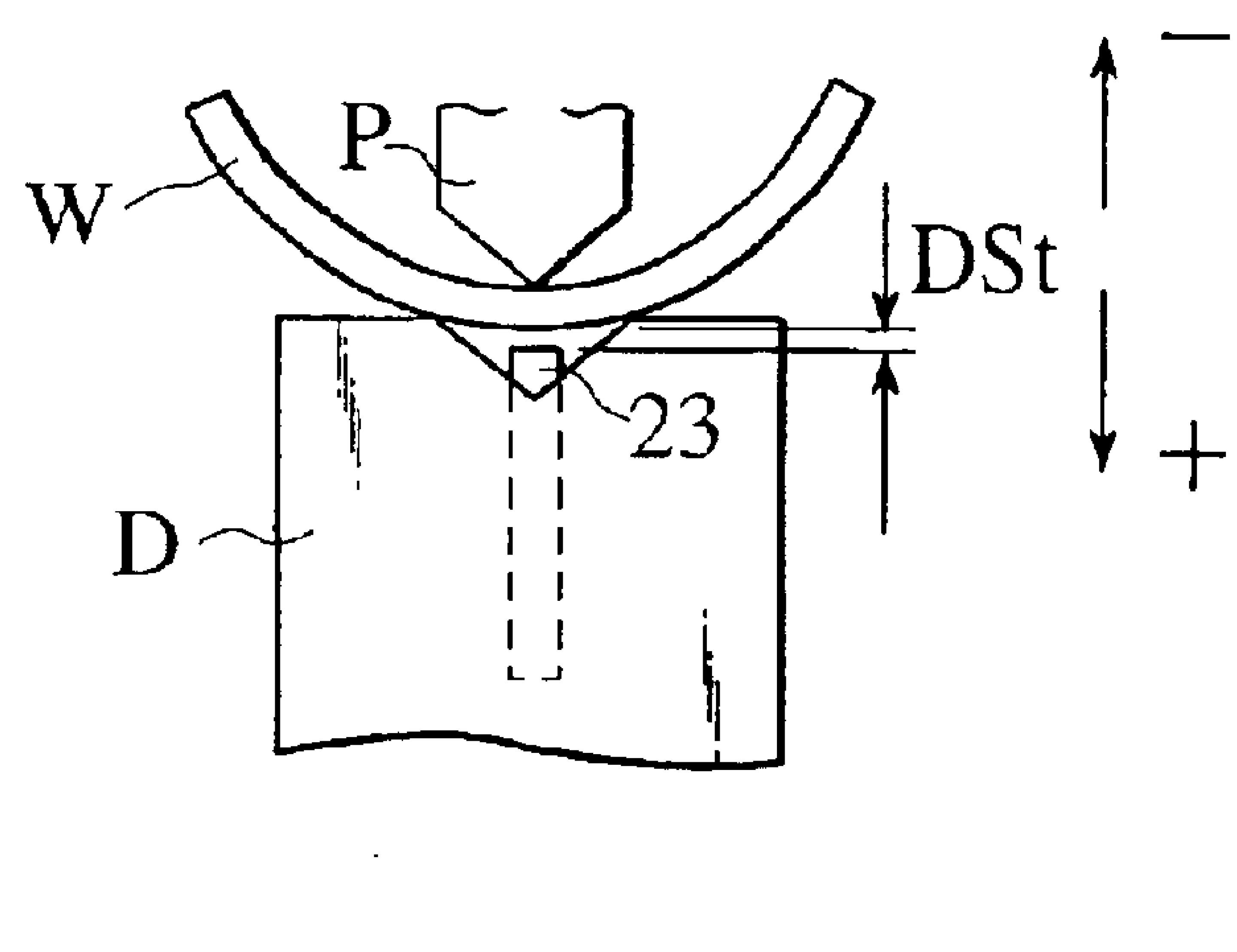


FIG. 11

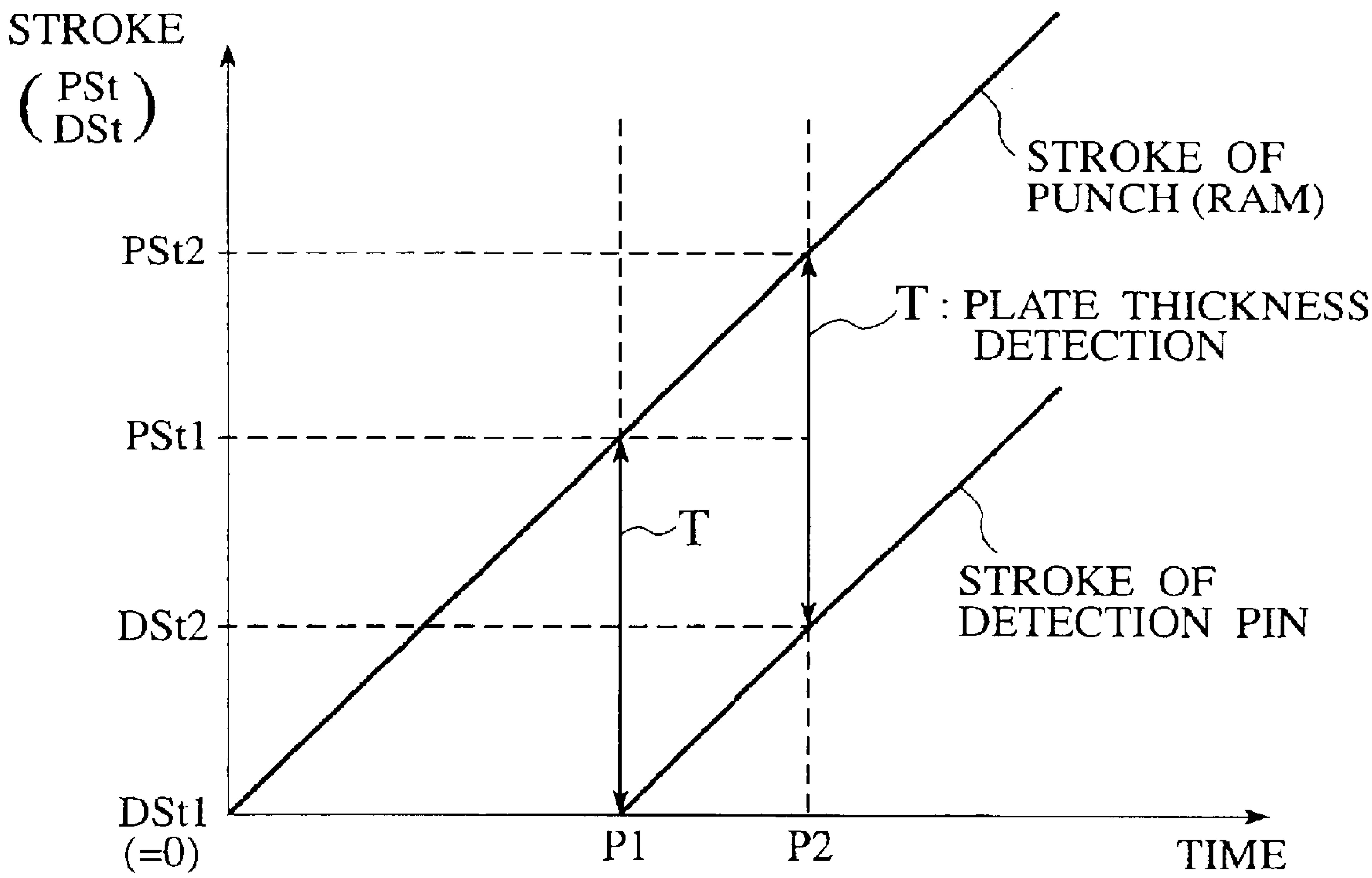

STROKE
(PSt / DSt)
PSt2
PSt1
DSt2
DSt1
(=0)
P1
P2
TIME
T
STROKE OF PUNCH (RAM)
T : PLATE THICKNESS DETECTION
STROKE OF DETECTION PIN

FIG. 12

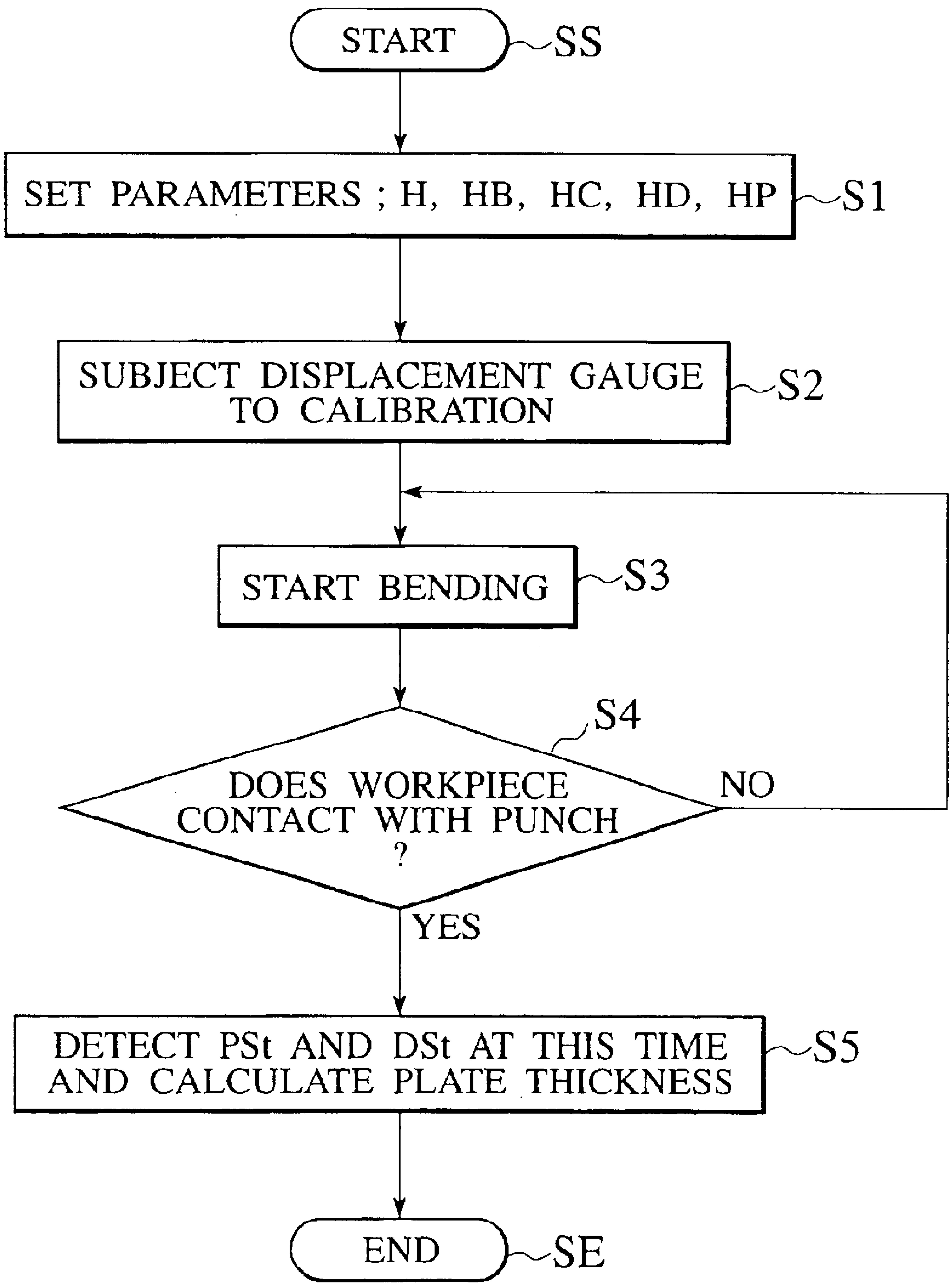

START
SS
SET PARAMETERS ; H, HB, HC, HD, HP
S1
SUBJECT DISPLACEMENT GAUGE TO CALIBRATION
S2
START BENDING
S3
S4
DOES WORKPIECE CONTACT WITH PUNCH ?
NO
YES
DETECT PSt AND DSt AT THIS TIME AND CALCULATE PLATE THICKNESS
S5
END
SE

FIG. 13

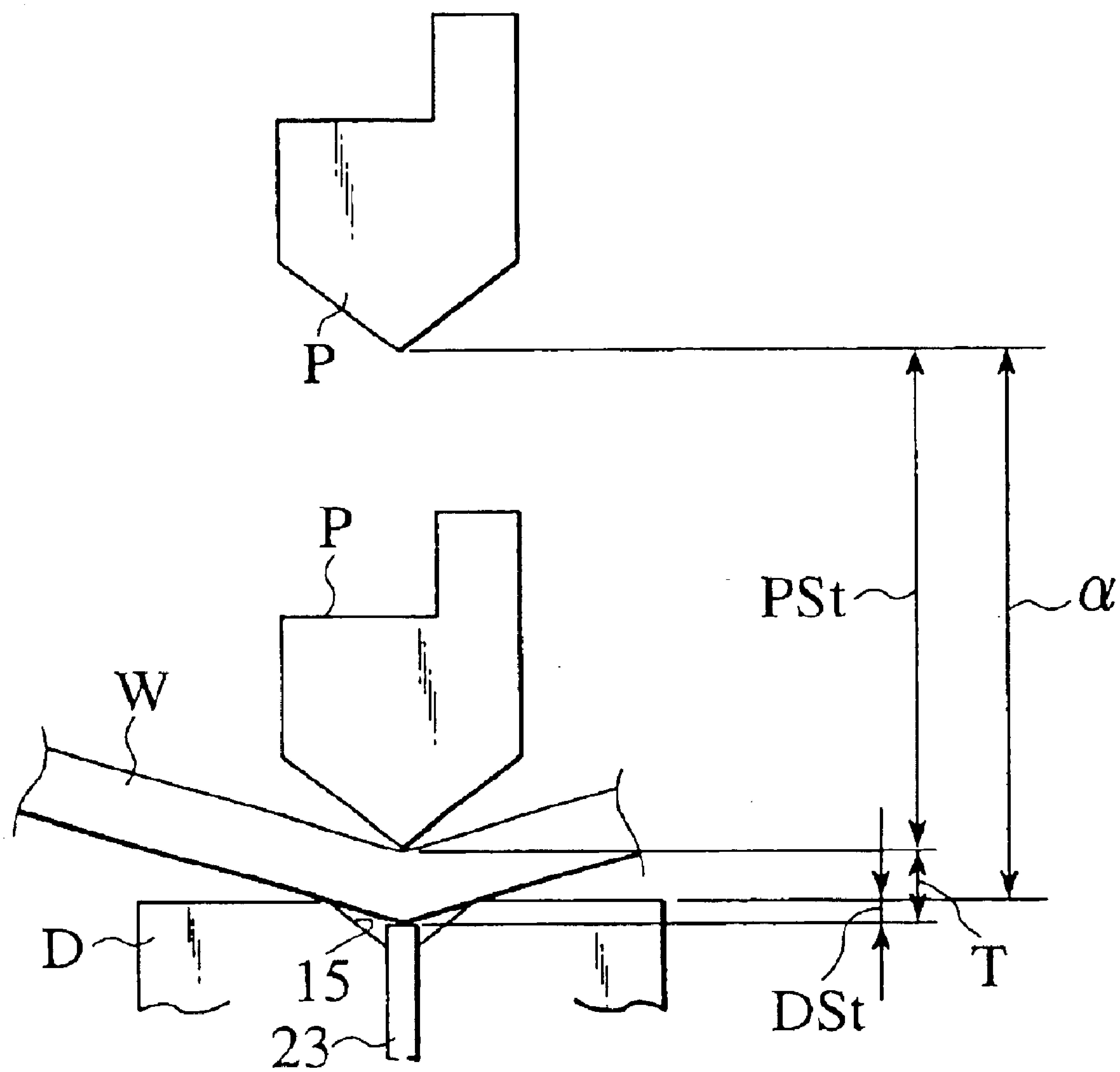


FIG. 14

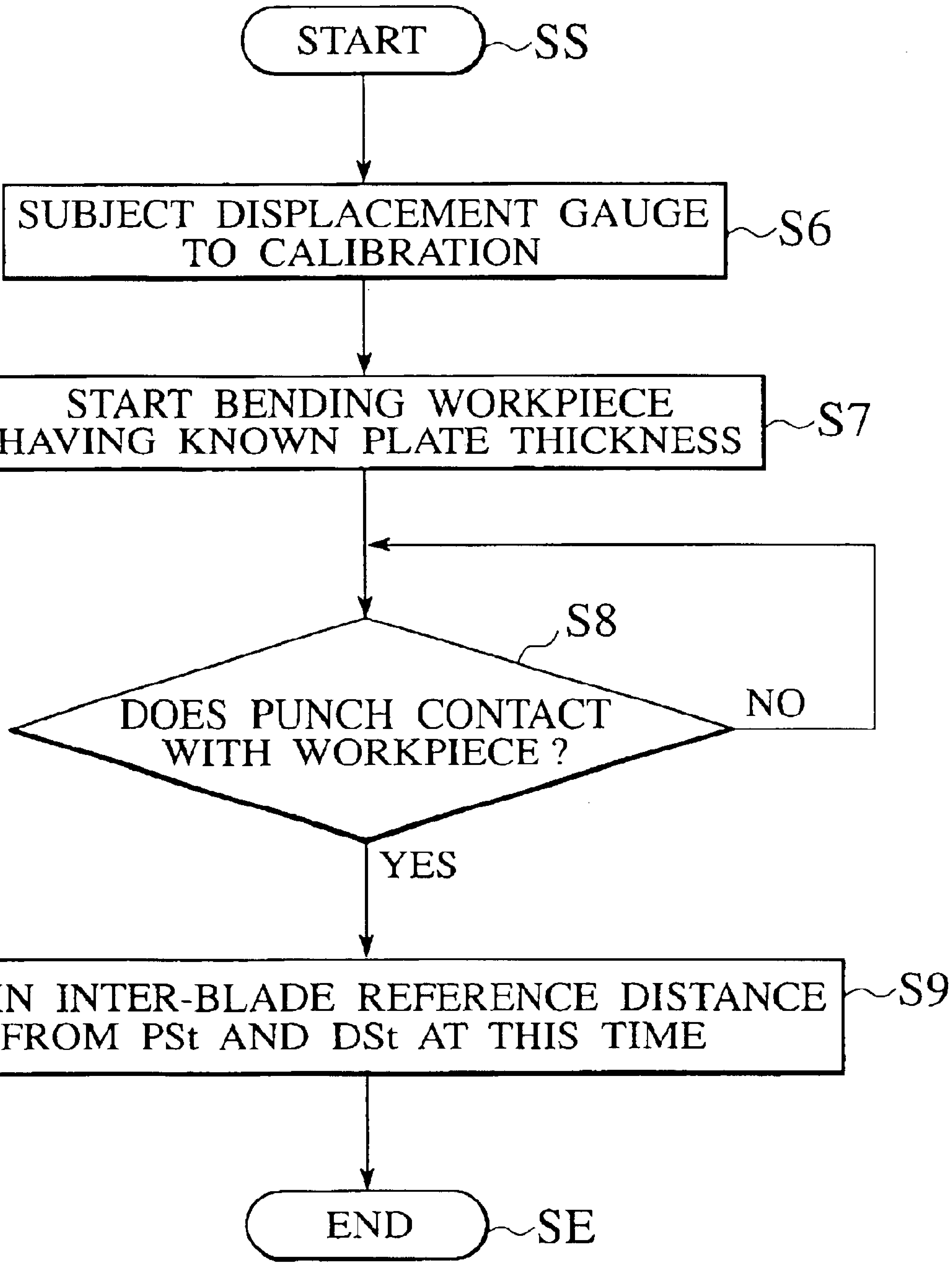

START
SS
SUBJECT DISPLACEMENT GAUGE TO CALIBRATION
S6
START BENDING WORKPIECE HAVING KNOWN PLATE THICKNESS
S7
S8
DOES PUNCH CONTACT WITH WORKPIECE ?
NO
YES
OBTAIN INTER-BLADE REFERENCE DISTANCE FROM PSt AND DSt AT THIS TIME
S9
END
SE

FIG. 15

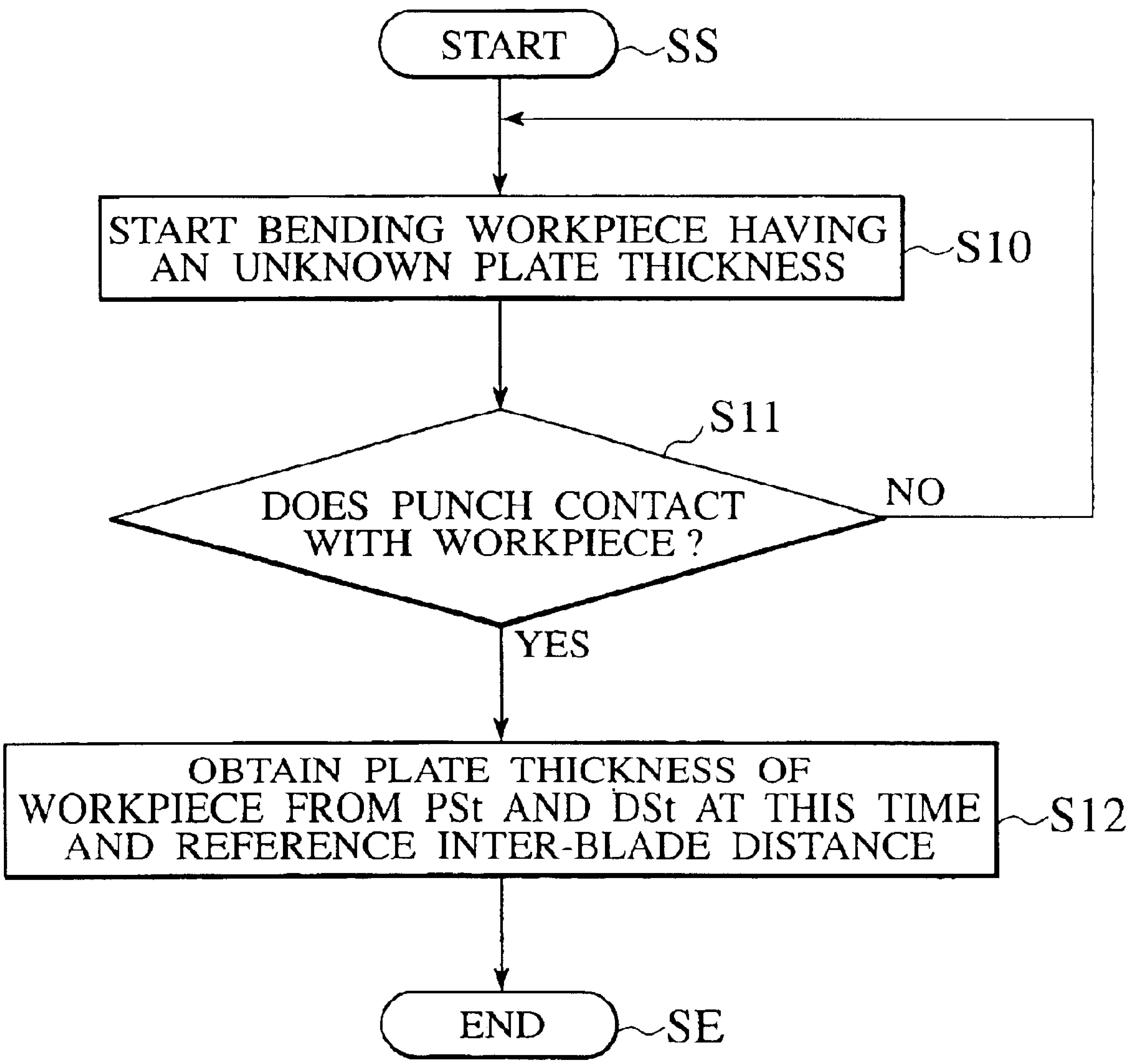
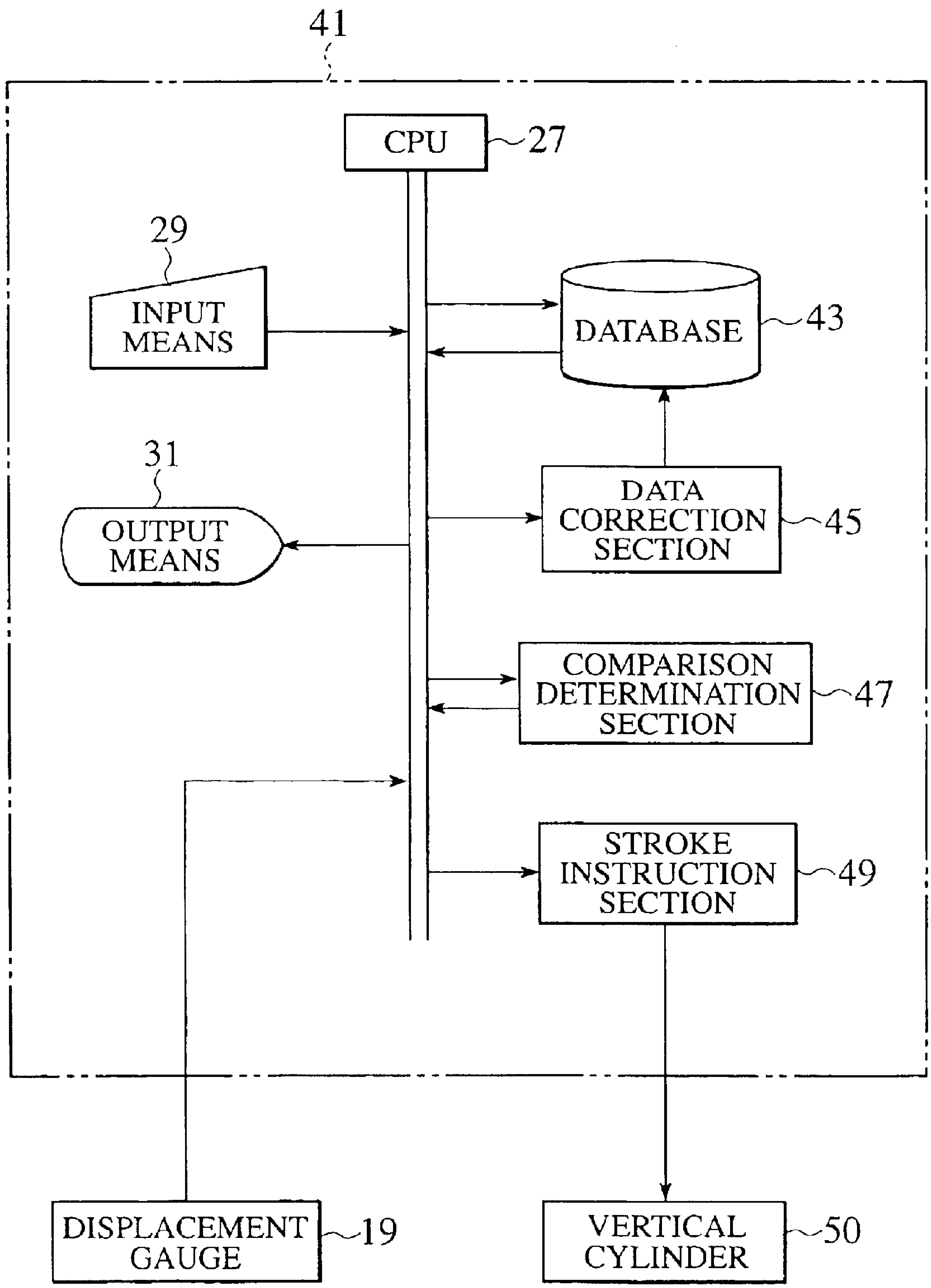

START
SS
START BENDING WORKPIECE HAVING AN UNKNOWN PLATE THICKNESS
S10
S11
DOES PUNCH CONTACT WITH WORKPIECE ?
NO
YES
OBTAIN PLATE THICKNESS OF WORKPIECE FROM PSt AND DSt AT THIS TIME AND REFERENCE INTER-BLADE DISTANCE
S12
END
SE

FIG. 16



41
CPU
27
29
INPUT MEANS
DATABASE
43
31
OUTPUT MEANS
DATA CORRECTION SECTION
45
COMPARISON DETERMINATION SECTION
47
STROKE INSTRUCTION SECTION
49
DISPLACEMENT GAUGE
19
VERTICAL CYLINDER
50

FIG. 17

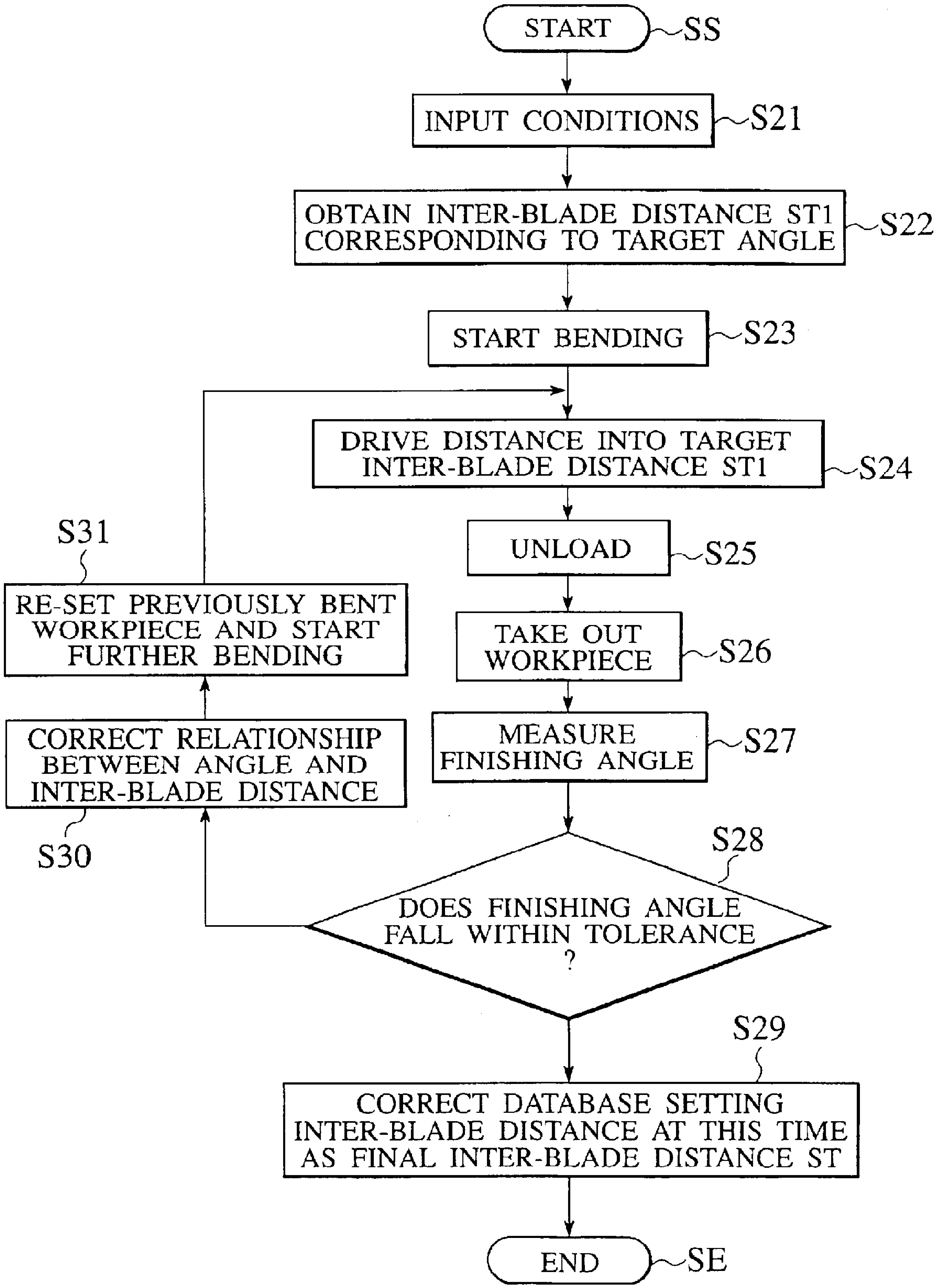

START
SS
INPUT CONDITIONS
S21
OBTAIN INTER-BLADE DISTANCE ST1 CORRESPONDING TO TARGET ANGLE
S22
START BENDING
S23
DRIVE DISTANCE INTO TARGET INTER-BLADE DISTANCE ST1
S24
UNLOAD
S25
TAKE OUT WORKPIECE
S26
MEASURE FINISHING ANGLE
S27
DOES FINISHING ANGLE FALL WITHIN TOLERANCE ?
S28
CORRECT DATABASE SETTING INTER-BLADE DISTANCE AT THIS TIME AS FINAL INTER-BLADE DISTANCE ST
S29
END
SE
CORRECT RELATIONSHIP BETWEEN ANGLE AND INTER-BLADE DISTANCE
S30
RE-SET PREVIOUSLY BENT WORKPIECE AND START FURTHER BENDING
S31

FIG. 18

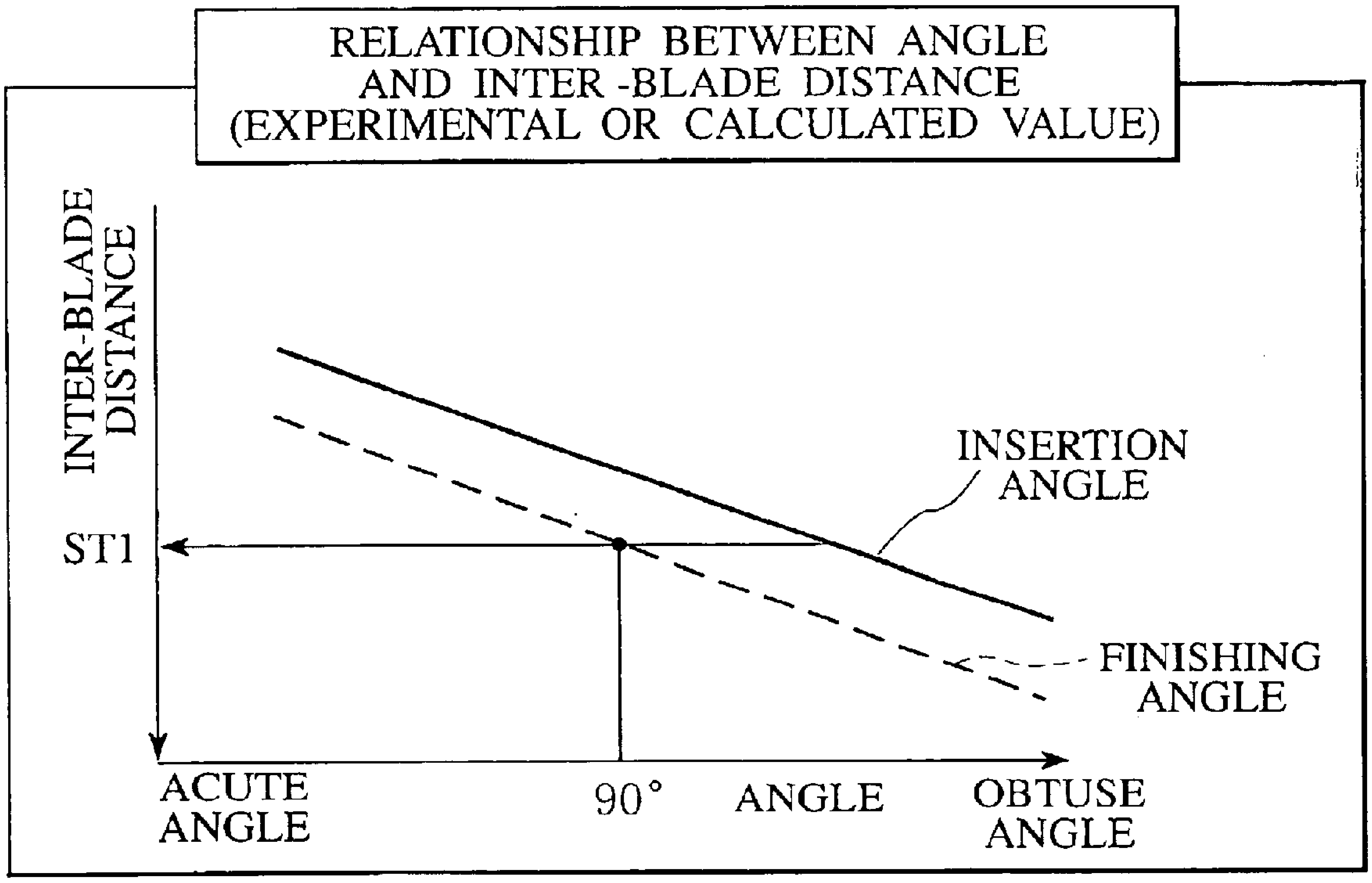

RELATIONSHIP BETWEEN ANGLE AND INTER -BLADE DISTANCE (EXPERIMENTAL OR CALCULATED VALUE)
INTER-BLADE DISTANCE
ST1
INSERTION ANGLE
FINISHING ANGLE
ACUTE ANGLE
90°
ANGLE
OBTUSE ANGLE

FIG. 19

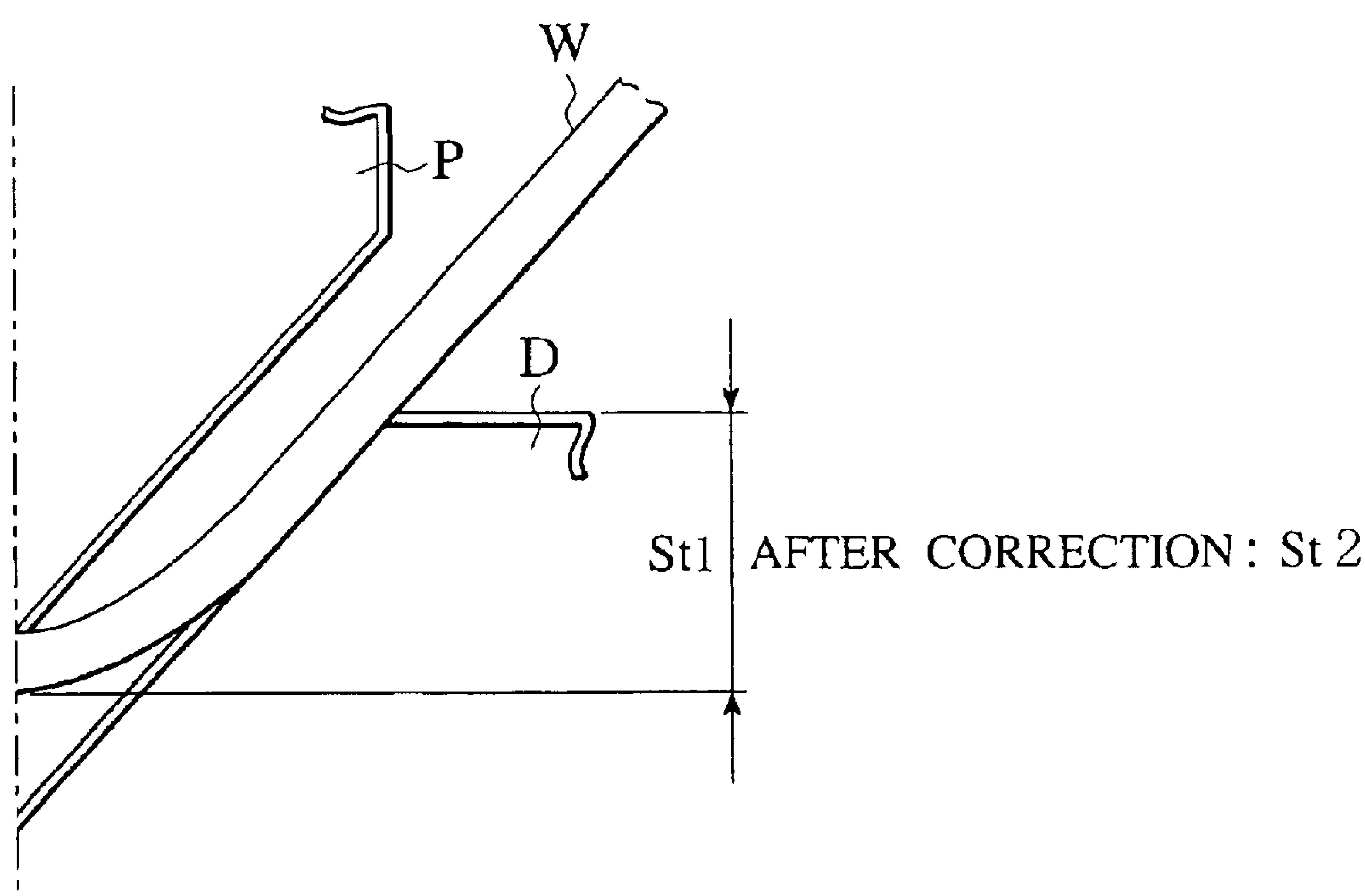

W
P
D
St1
AFTER CORRECTION : St 2

FIG. 20

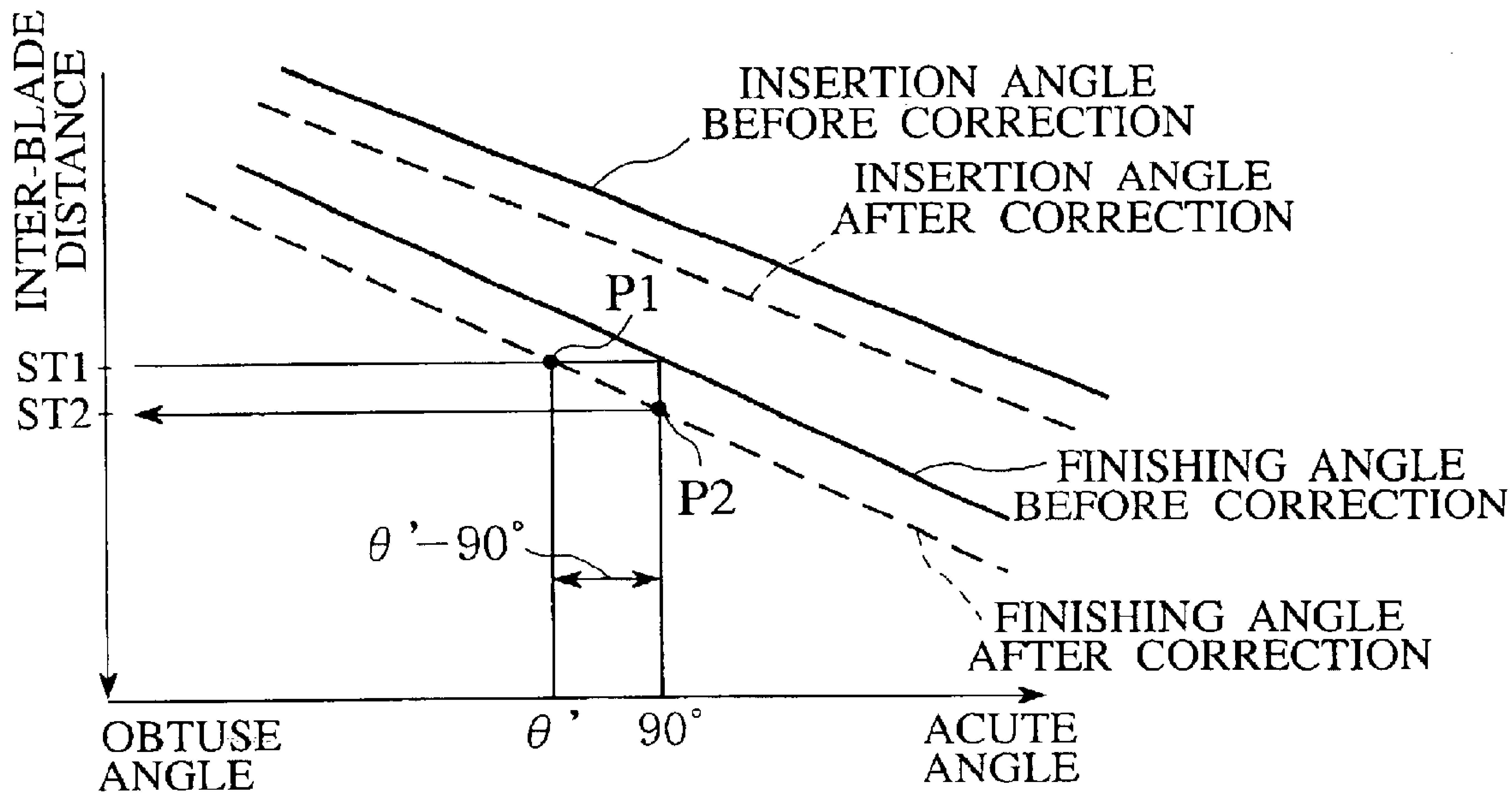

INTER-BLADE DISTANCE
INSERTION ANGLE BEFORE CORRECTION
INSERTION ANGLE AFTER CORRECTION
P1
ST1
ST2
P2
FINISHING ANGLE BEFORE CORRECTION
θ'−90°
FINISHING ANGLE AFTER CORRECTION
OBTUSE ANGLE
θ'
90°
ACUTE ANGLE

FIG. 21

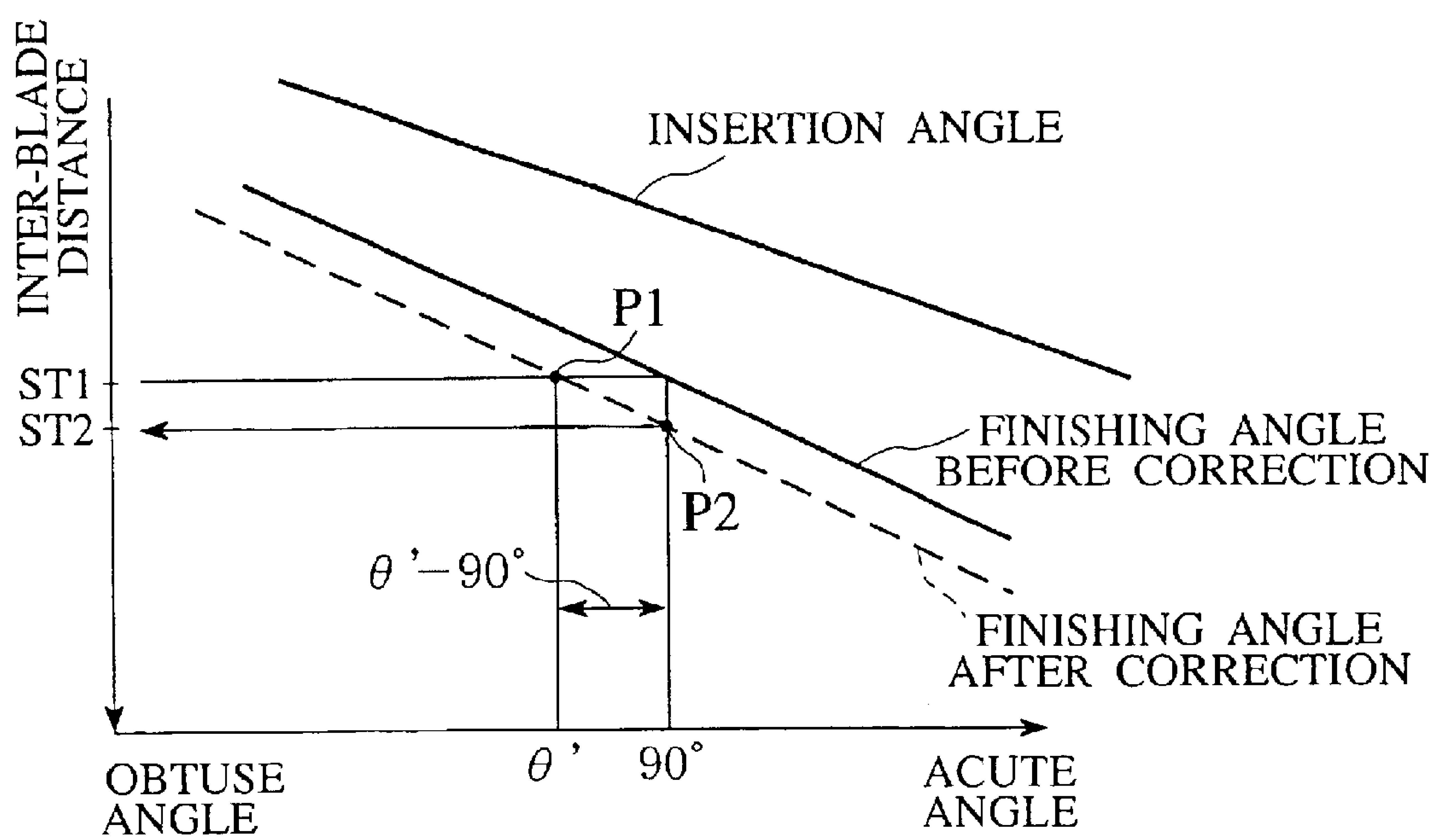

INTER-BLADE DISTANCE
INSERTION ANGLE
P1
ST1
ST2
FINISHING ANGLE BEFORE CORRECTION
P2
θ'−90°
FINISHING ANGLE AFTER CORRECTION
OBTUSE ANGLE
θ'
90°
ACUTE ANGLE

FIG. 22

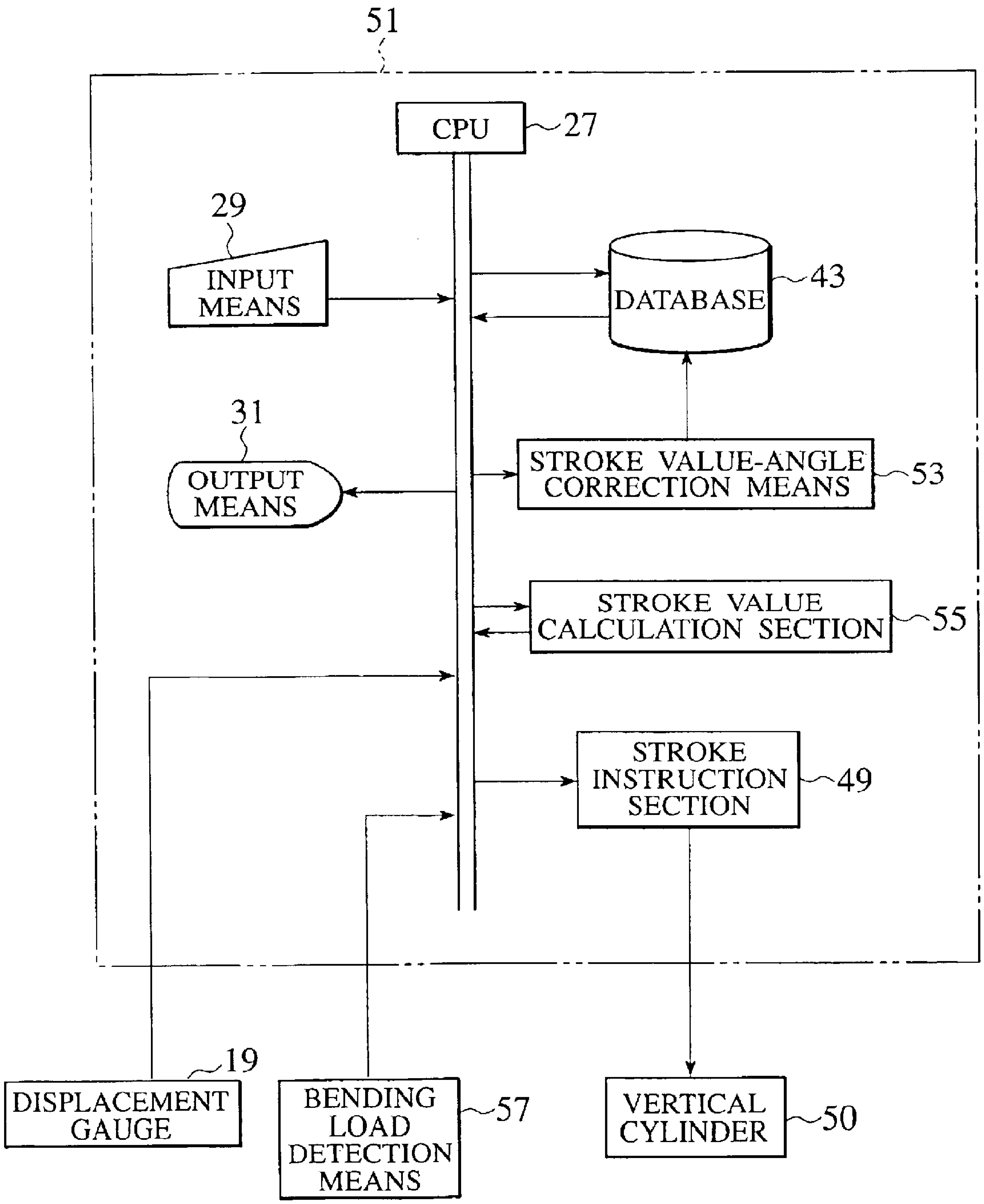

51
CPU
27
29
INPUT MEANS
DATABASE
43
31
OUTPUT MEANS
STROKE VALUE-ANGLE CORRECTION MEANS
53
STROKE VALUE CALCULATION SECTION
55
STROKE INSTRUCTION SECTION
49
19
DISPLACEMENT GAUGE
BENDING LOAD DETECTION MEANS
57
VERTICAL CYLINDER
50

FIG. 23

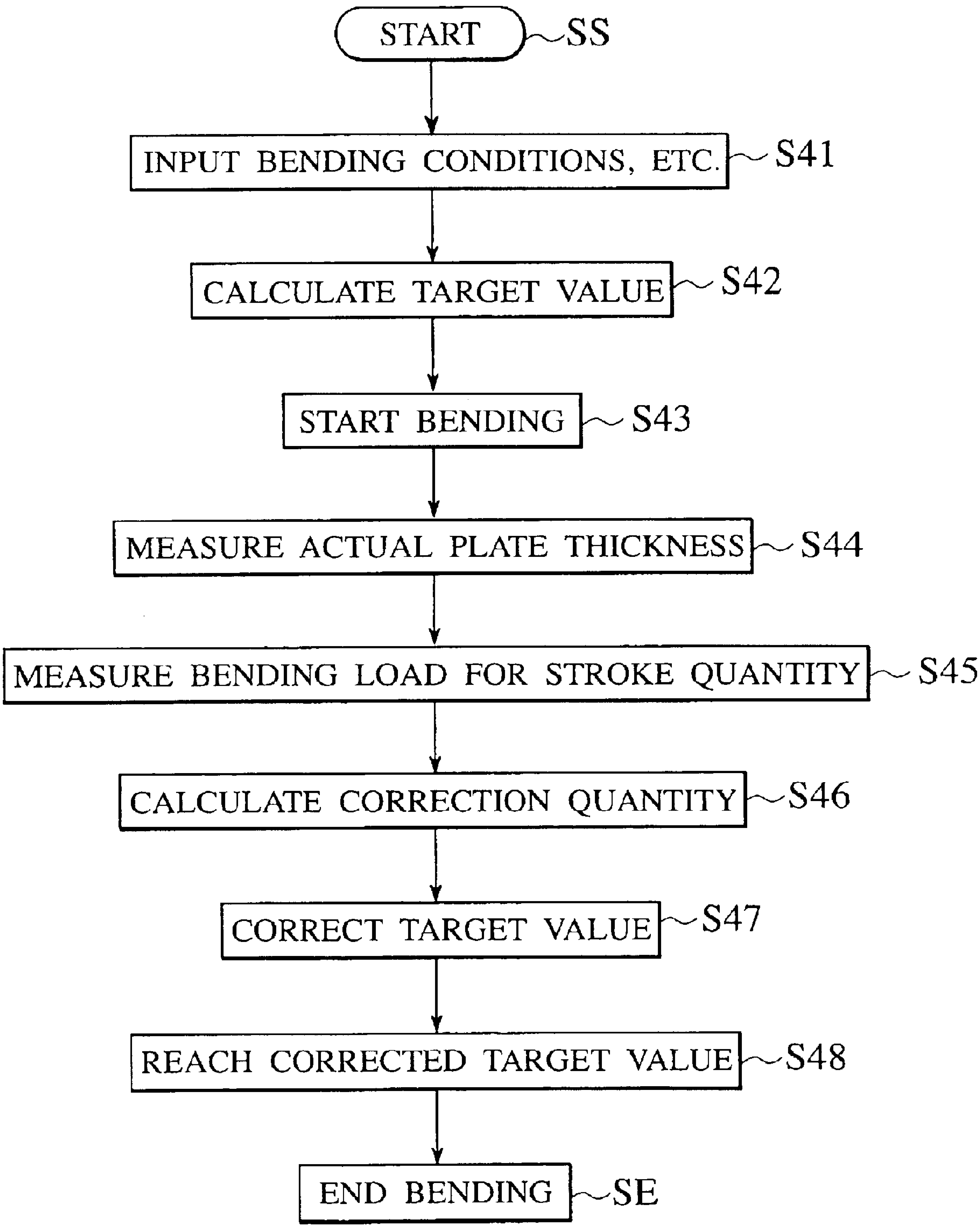

START
SS
INPUT BENDING CONDITIONS, ETC.
S41
CALCULATE TARGET VALUE
S42
START BENDING
S43
MEASURE ACTUAL PLATE THICKNESS
S44
MEASURE BENDING LOAD FOR STROKE QUANTITY
S45
CALCULATE CORRECTION QUANTITY
S46
CORRECT TARGET VALUE
S47
REACH CORRECTED TARGET VALUE
S48
END BENDING
SE

FIG. 24

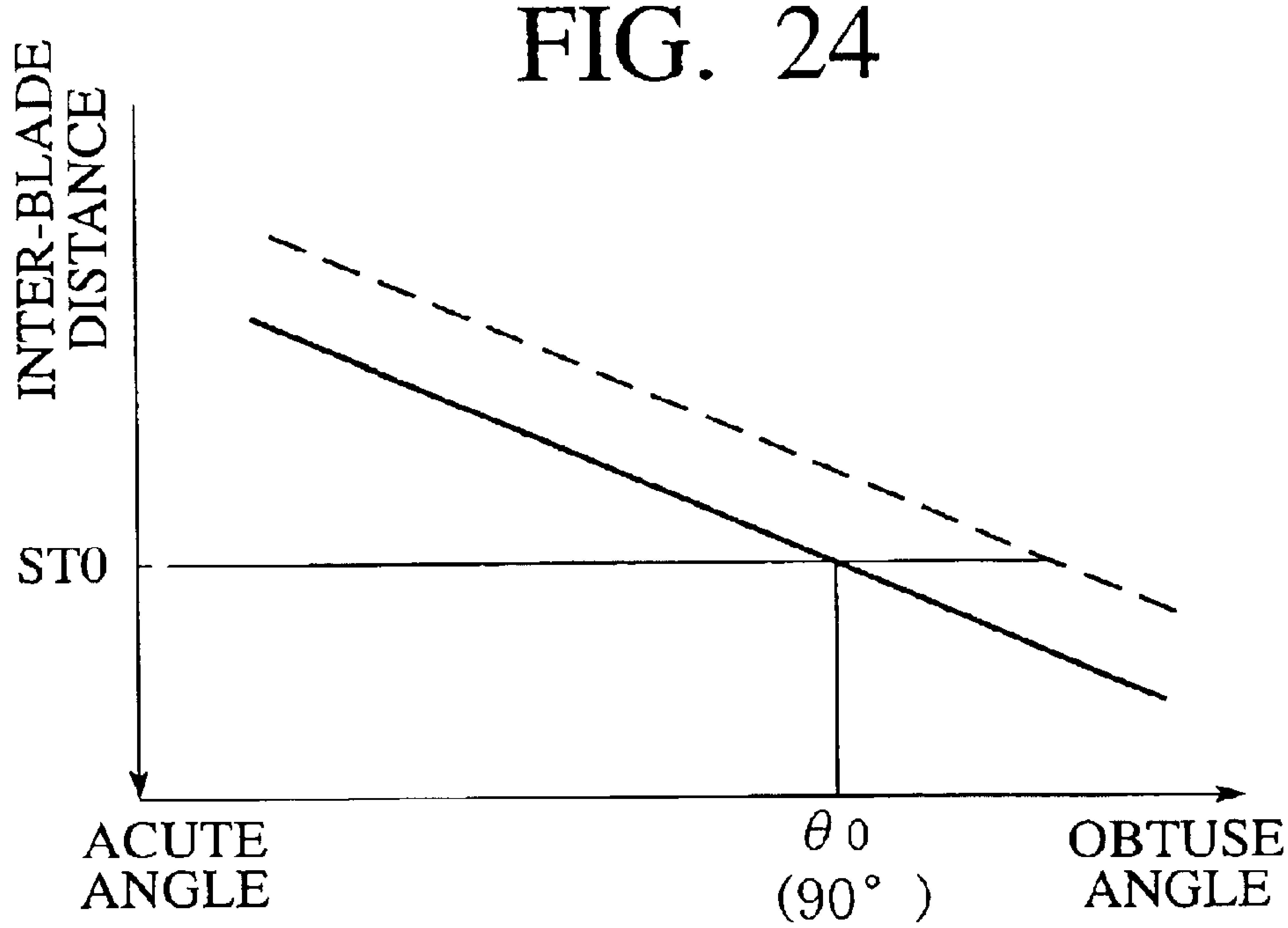

INTER-BLADE DISTANCE
ST0
ACUTE ANGLE
θ0
(90°)
OBTUSE ANGLE

FIG. 25

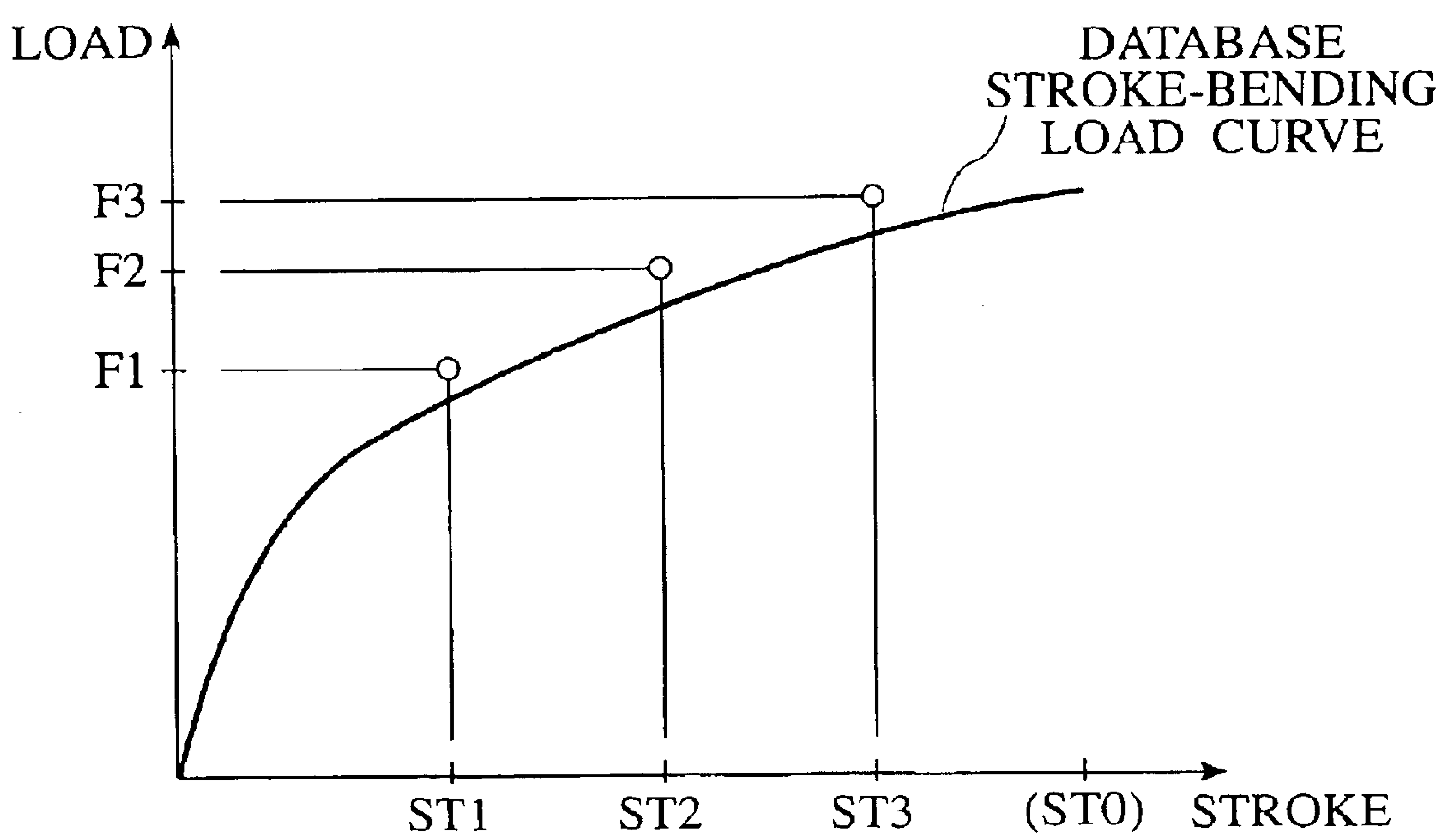

LOAD
DATABASE STROKE-BENDING LOAD CURVE
F3
F2
F1
ST1
ST2
ST3
(ST0)
STROKE

FIG. 26

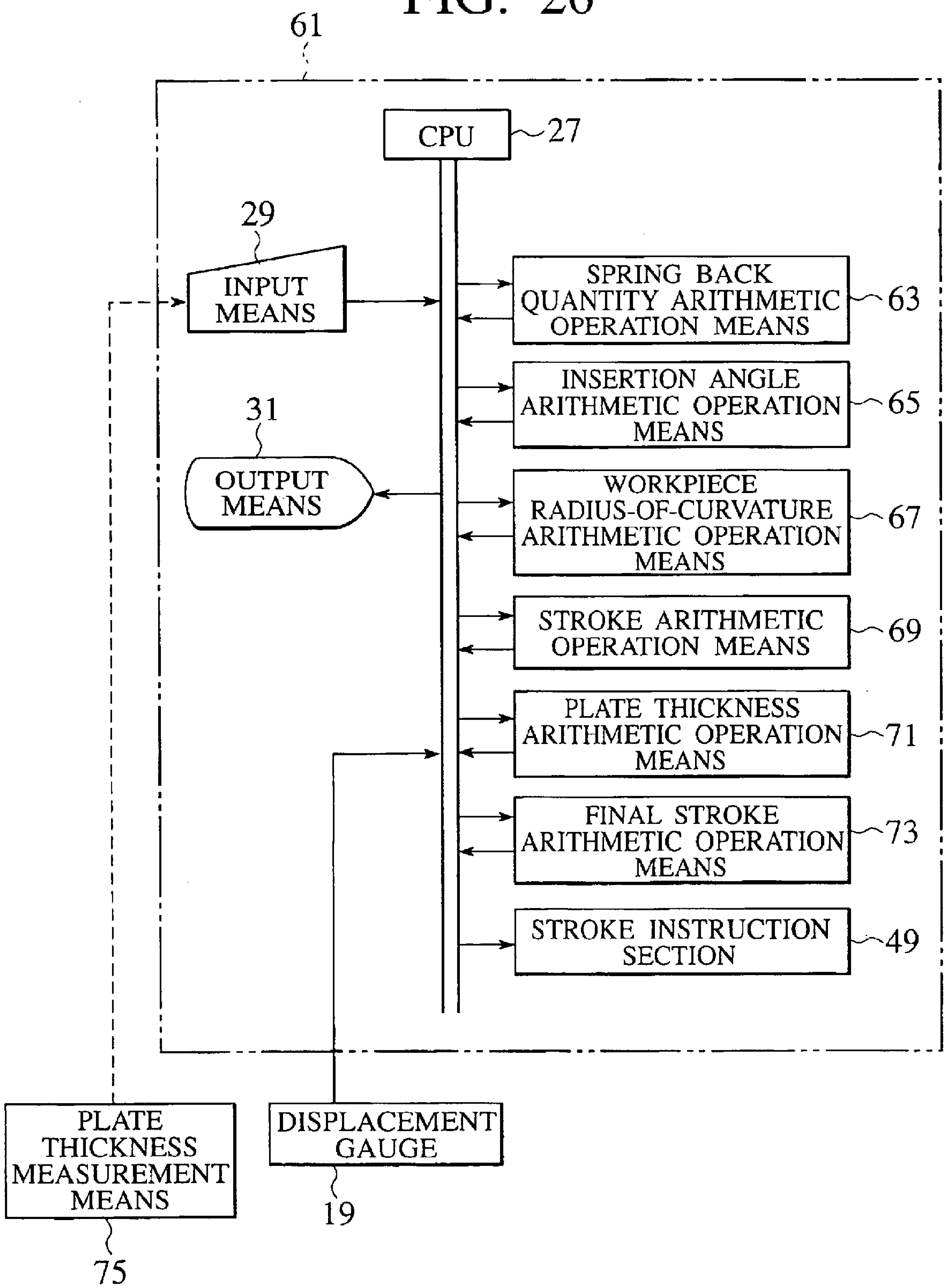

61
CPU
27
29
INPUT MEANS
31
OUTPUT MEANS
SPRING BACK QUANTITY ARITHMETIC OPERATION MEANS
63
INSERTION ANGLE ARITHMETIC OPERATION MEANS
65
WORKPIECE RADIUS-OF-CURVATURE ARITHMETIC OPERATION MEANS
67
STROKE ARITHMETIC OPERATION MEANS
69
PLATE THICKNESS ARITHMETIC OPERATION MEANS
71
FINAL STROKE ARITHMETIC OPERATION MEANS
73
STROKE INSTRUCTION SECTION
49
PLATE THICKNESS MEASUREMENT MEANS
75
DISPLACEMENT GAUGE
19

FIG. 27

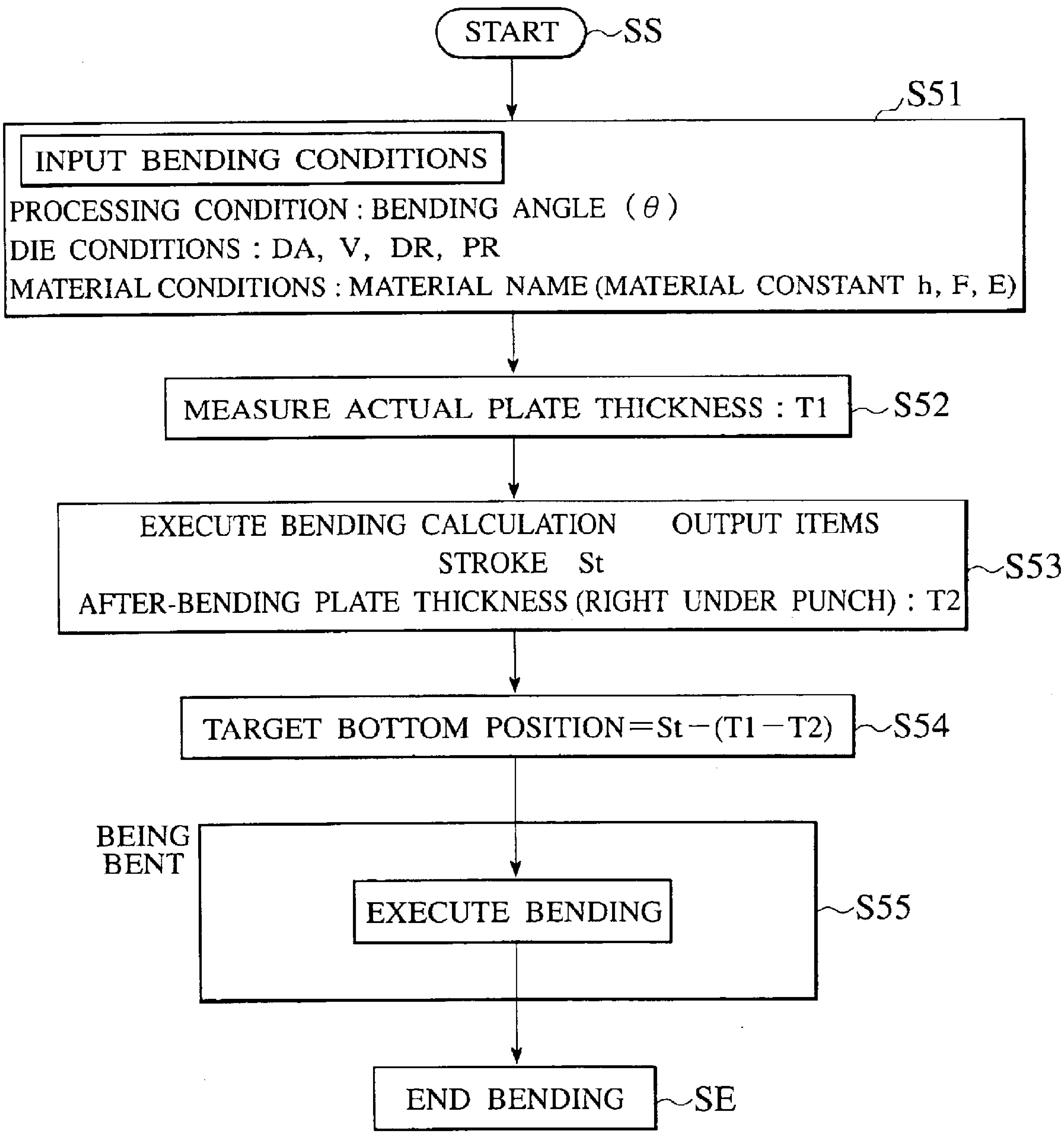

START
SS
S51
INPUT BENDING CONDITIONS
PROCESSING CONDITION : BENDING ANGLE (θ)
DIE CONDITIONS : DA, V, DR, PR
MATERIAL CONDITIONS : MATERIAL NAME (MATERIAL CONSTANT h, F, E)
MEASURE ACTUAL PLATE THICKNESS : T1
S52
EXECUTE BENDING CALCULATION OUTPUT ITEMS
STROKE St
AFTER-BENDING PLATE THICKNESS (RIGHT UNDER PUNCH) : T2
S53
TARGET BOTTOM POSITION=St−(T1−T2)
S54
BEING BENT
EXECUTE BENDING
S55
END BENDING
SE

FIG. 28

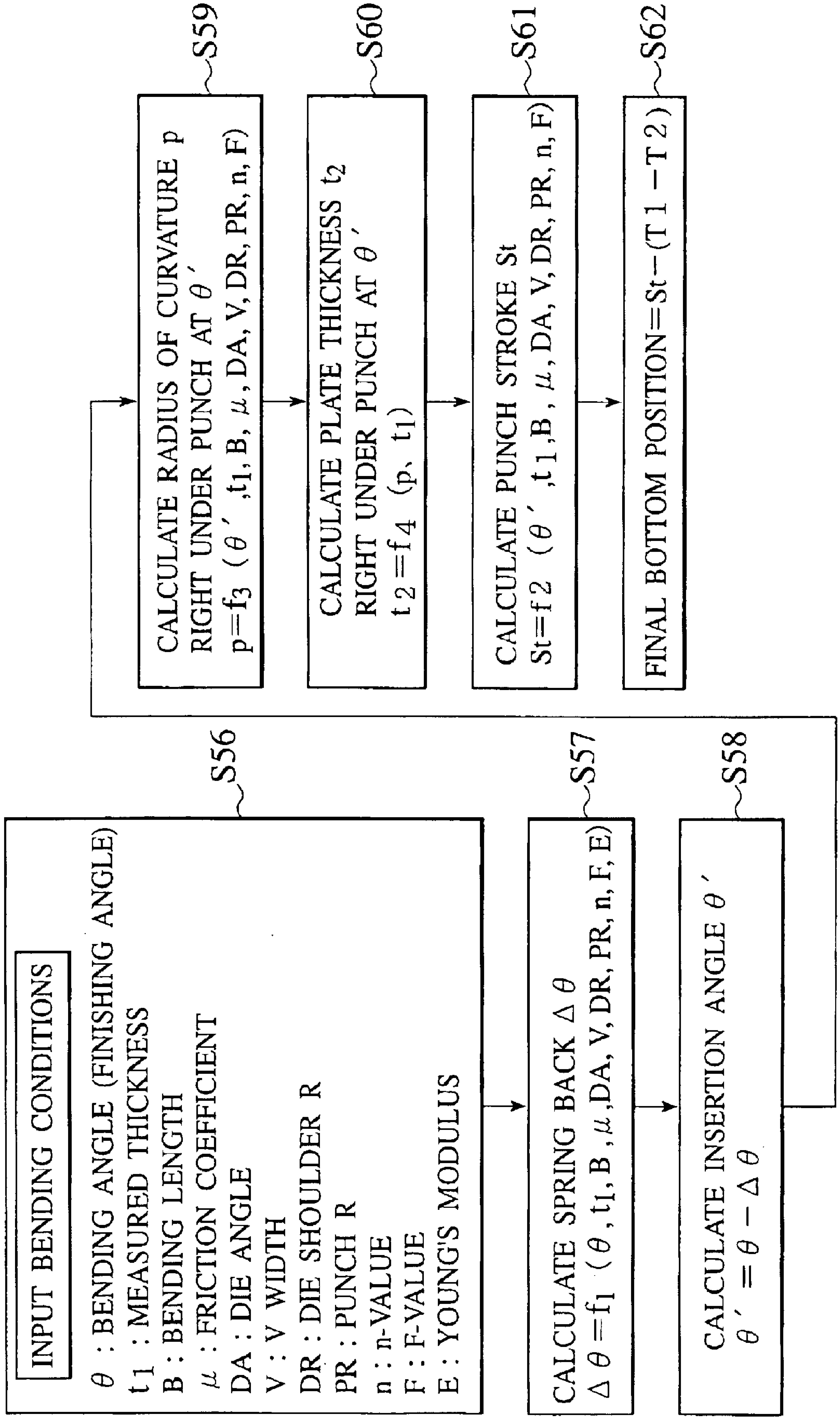

INPUT BENDING CONDITIONS
θ : BENDING ANGLE (FINISHING ANGLE)
t1 : MEASURED THICKNESS
B : BENDING LENGTH
μ : FRICTION COEFFICIENT
DA : DIE ANGLE
V : V WIDTH
DR : DIE SHOULDER R
PR : PUNCH R
n : n-VALUE
F : F-VALUE
E : YOUNG'S MODULUS
S56
CALCULATE SPRING BACK Δθ
Δθ=f1 (θ, t1, B, μ, DA, V, DR, PR, n, F, E)
S57
CALCULATE INSERTION ANGLE θ′
θ′ = θ − Δθ
S58
CALCULATE RADIUS OF CURVATURE p
RIGHT UNDER PUNCH AT θ′
p=f3 (θ′, t1, B, μ, DA, V, DR, PR, n, F)
S59
CALCULATE PLATE THICKNESS t2
RIGHT UNDER PUNCH AT θ′
t2=f4 (p, t1)
S60
CALCULATE PUNCH STROKE St
St=f2 (θ′, t1, B, μ, DA, V, DR, PR, n, F)
S61
FINAL BOTTOM POSITION=St−(T1 −T2)
S62

FIG. 29

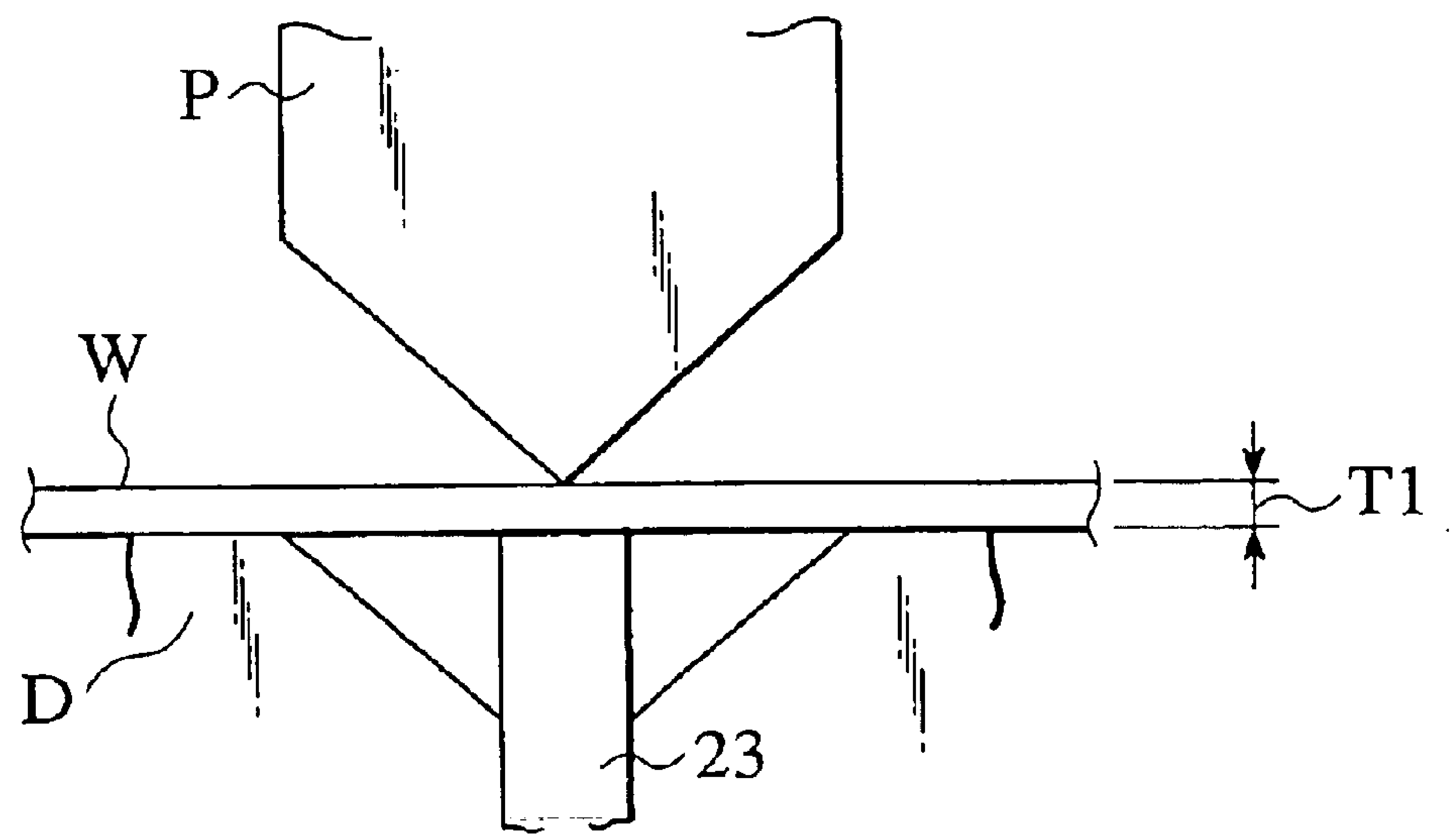


FIG. 30

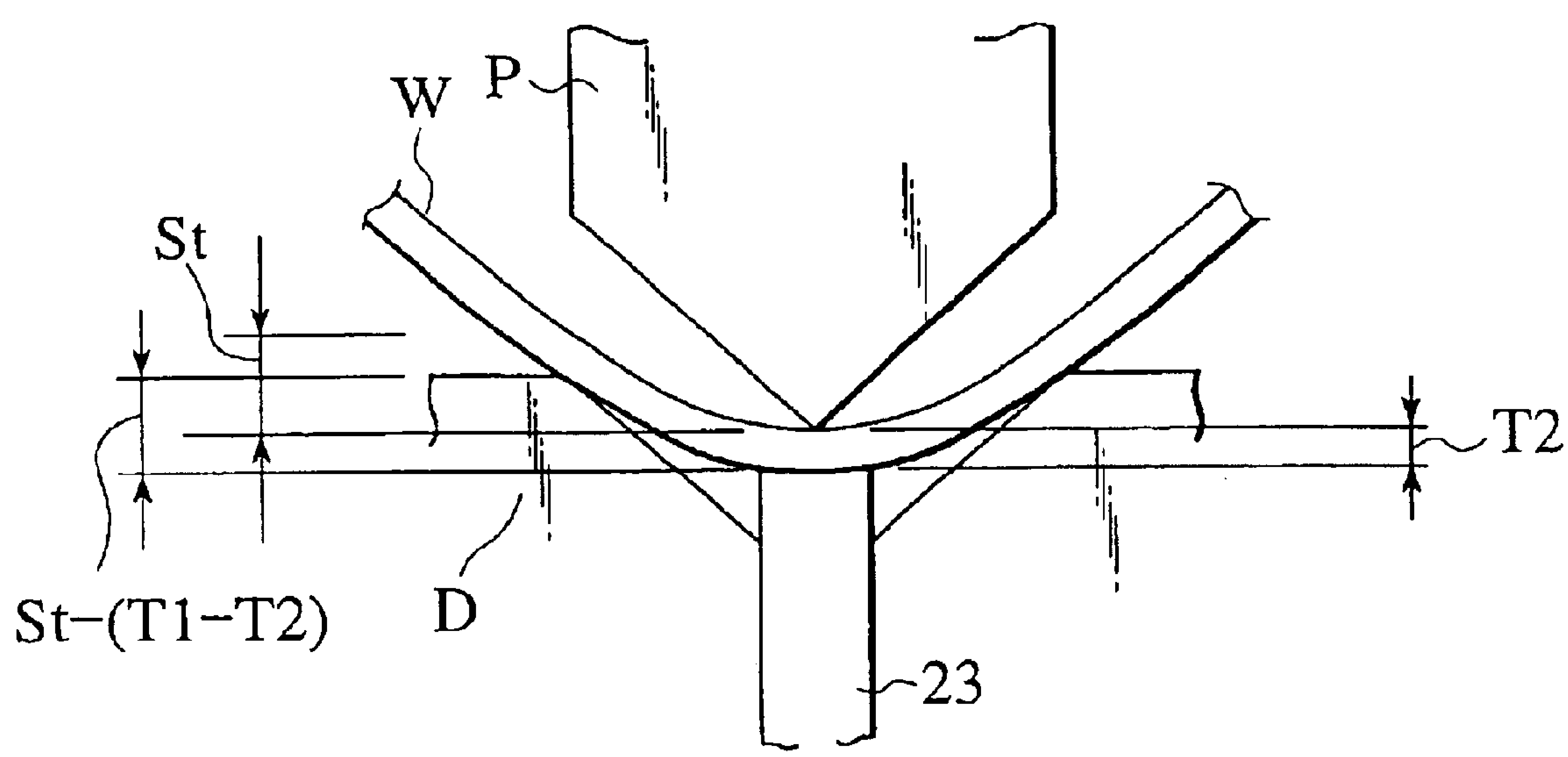
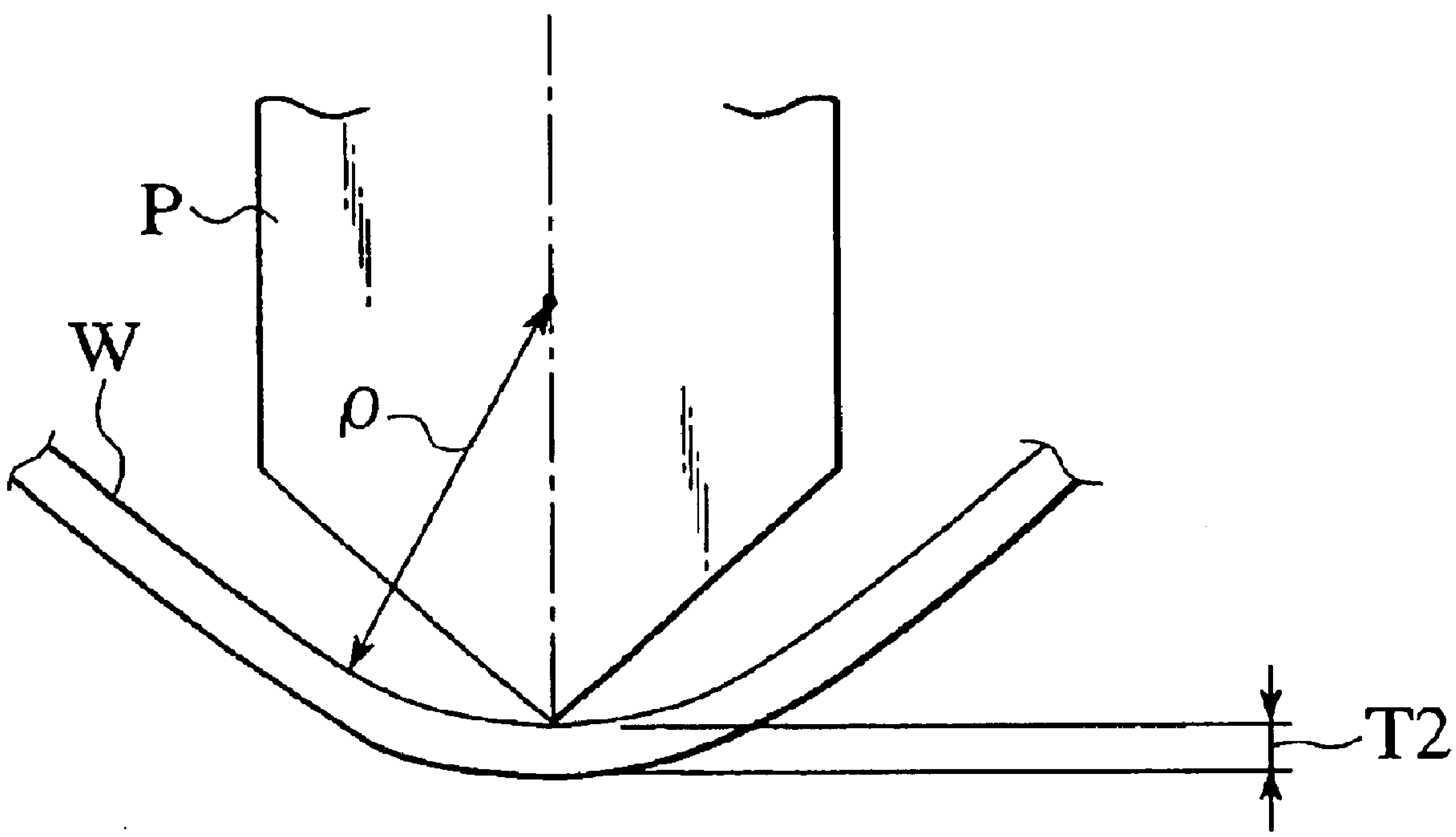


FIG. 31



SHEET THICKNESS DETECTING METHOD AND DEVICE THEREFOR IN BENDING MACHINE, REFERENCE INTER-BLADE DISTANCE DETECTING METHOD AND DEVICE THEREFOR, AND BENDING METHOD AND BENDING DEVICE

TECHNICAL FIELD

The present invention relates to a plate thickness detection method, a plate thickness detector, a reference inter-blade distance detection method, and a reference inter-blade distance detector for a bending machine for bending a workpiece by causing a punch to make a relative stroke and to cooperate with a die in the bending.

In addition, the present invention relates to a bending method and a bending apparatus for directly detecting the relative stroke value of a punch to a die and controlling the relative stroke of the punch by a vertically movable displacement gauge which is provided in the die and protruded from the V groove of the die.

The present invention also relates to a bending method and a bending apparatus capable of conducting accurate bending by calculating a D-value in light of a change in the plate thickness of a workpiece which is generated during the bending.

BACKGROUND ART OF THE INVENTION

According to conventional bending, a nominal plate thickness is input to an NC device and a D-value for a desired bending angle is thereby calculated. An actual plate thickness, however, varies according to the difference in manufacturer or a lot and a desired angle cannot be often obtained.

Considering this, as disclosed in Japanese Patent Application Laid-Open No. 63-157722, the relative pressure of a punch against a die from the torque of a servo motor elevating a ram is measured, and a position corresponding to a rising point of torque is considered as a workpiece upper position so as to detect a plate thickness.

Further, as disclosed in Japanese Patent Application Laid-Open No. 6-74746, a plate thickness is measured by setting a point at which the difference between a linear scale value and an NC device instruction value occurs based on the backlash of a ball screw which drives a ram, as a reference point at which a punch contacts with a workpiece.

However, in the method disclosed in 63-157722, it is disadvantageously difficult to detect the rising of pressure for a thin workpiece.

Further, as in the case of the method disclosed in 6-74746, if a point at which the difference between a linear scale value and an NC device instruction value occurs based on the backlash is determined as a point at which a punch contacts with a workpiece, “an excessive lash” which causes a backlash to enable detection is necessary. This makes it disadvantageously impossible to apply this method to a hydraulic bending machine.

Meanwhile, as shown in FIG. **1**, if a workpiece W is bent by a punch P and a die D cooperatively in a press brake, for example, as a bending apparatus, a ram position detection means **103** for detecting the upper and lower positions of a ram **101** is provided so as to measure the distance between the punch P and the die D to thereby obtain a predetermined bending angle. A D-value is calculated in light of die conditions, workpiece conditions and the like, the ram

position detection means **103** controls the D-value to bend the workpiece W.

However, even if the predetermined D-value is calculated and the relative distance of the punch P to the die D is controlled to obtain the D-value, mechanical deflections such as the deflections of side plates, those of upper and lower tables and that of the die occur due to the bending reaction of the workpiece W during the bending. Unless these deflections are corrected, bending with accurate angle cannot be ensured. However, it is quite difficult to accurately calculate and correct these mechanical deflections.

To solve this, as disclosed in, for example, Japanese Utility Model Application Publication No. 6-49374, there is proposed a bending method for directly detecting a D-value without the need to consider mechanical deflections. That is, as shown in FIG. **2**, this position detection means **105** has a vertically movable detection pin **109** protruded from a V groove **107** of a die D and provided in the die D to be always urged upward, and detects the vertical movement of the detection pin **109** using a displacement gauge **111**.

Therefore, if a punch P descends to thereby bend the workpiece W downward, then the lower surface of the workpiece W which is being bent is abutted on the detection pin **109** to press the pin **109** down. The descent of the detection pin **109** is detected by the displacement gauge **111** to thereby directly detect a D-value.

Even with the conventional art, however, it is difficult to accurately calculate the relative stroke value of the punch P to obtain a target bending angle because of the various characteristics of the workpiece W, e.g., spring-back by which if the workpiece W is unloaded after being bent, the bending angle recovers.

On the other hand, with both the method shown in 63-15772 and that shown in 6-74746 as described above, a phenomenon that the actual plate thickness of the workpiece changes (decreases) during bending occurs. According to each method, the D-value is calculated not in light of the decrease of the thickness but based on the detection of the position at which the punch contacts with the workpiece at the start of bending. Since the D-value is not calculated in light of the thickness change (decrease) after the bending completely starts, the method has a disadvantage in that a target angle cannot be accurately obtained.

The present invention has been made while paying attention to the above-stated conventional disadvantages and the object of the present invention is to provide a plate thickness detection method, a plate thickness detector, a reference inter-blade distance detection method and a reference inter-blade distance detector for a bending machine capable of accurately detecting the actual plate thickness of a workpiece during bending.

Further, the present invention has been made while paying attention to the above-stated conventional disadvantages and the object of the present invention is to provide a bending method and a bending apparatus capable of accurately calculating the relative stroke value of a punch for a target bending angle and carrying out bending with high accuracy.

DISCLOSURE OF THE INVENTION

To attain the above object, the invention is a plate thickness detection method for a bending machine causing a punch to make a relative stroke and bending a workpiece mounted on an upper surface of a die cooperatively by the punch and the die, characterized by relatively descending the punch from a reference position away from the die by a reference inter-blade distance; detecting a relative stroke quantity of the punch if a change in a displacement quantity of a displacement gauge provided in the die, always urged upward from a die V-groove, and measuring a distance to a lower surface of the workpiece is detected, or at a predetermined point after the detection, using a ram position detection means and detecting the displacement quantity of the displacement gauge at this time; and subtracting the detected relative stroke quantity from the reference inter-blade distance and adding the displacement quantity of the displacement gauge to the subtraction result, thereby detecting a plate thickness of the workpiece.

Further, the invention is characterized not only by the previously noted features of the invention, but also in that the reference inter-blade distance is a distance between the punch and the die at a top dead center before relatively descending the punch.

Further, the invention is characterized not only by the above-noted features of the invention, but also in that the reference inter-blade distance is calculated by mounting a workpiece having a known plate thickness on the die before actual bending, relatively descending the punch to detect the stroke quantity using ram position detection means and to detect the displacement quantity of the displacement gauge at this time, adding the plate thickness of the workpiece to the relative stroke quantity of the punch and subtracting the displacement quantity of the displacement gauge from the addition result.

To obtain the above object, the invention is a reference inter-blade distance detection method for obtaining a reference inter-blade distance which is a distance between a punch and a die at an arbitrary reference position, characterized by: mounting a workpiece having a known plate thickness on the die; relatively moving the punch to allow the punch to bend the workpiece cooperatively with the die; adding the known plate thickness to a stroke quantity of the punch at this time and subtracting a displacement quantity of a displacement gauge, provided in the die and detecting a distance from an upper surface of the die to a lower surface of the workpiece, from the addition result, thereby detecting the reference inter-blade distance.

To attain the above object, the invention is a plate thickness detector for a bending machine causing a punch to make a relative stroke and bending a workpiece mounted on an upper surface of a die cooperatively by the punch and the die, characterized by comprising: a displacement gauge provided in the die, always urged upward from a V-groove of the die, and measuring a distance from the upper surface of the die to a lower surface of the workpiece; ram position detection means for detecting a relative stroke quantity of the punch to the die; and a plate thickness arithmetic operation section calculating a plate thickness of the workpiece from a reference inter-blade distance which is a distance between the punch and the die, the distance being input or stored in storage means, a displacement quantity measured by the displacement gauge and the relative stroke quantity of the punch detected by the ram position detection means, and characterized in that the plate thickness arithmetic operation section detects the relative stroke quantity of the punch using ram position detection means at a point at which descent of the workpiece is detected by the displacement gauge or a predetermined point after the point after the punch is relatively descended from a position away from the die by the reference inter-blade distance, detects the displacement quantity of the displacement gauge at this time, and detects the plate thickness of the workpiece by subtracting the detected relative stroke quantity from the reference inter-blade distance and adding the displacement quantity to the subtraction result.

Further, the invention is characterized not only by the above-noted features of the invention, but also in that the reference inter-blade distance is a distance between the punch and the die at a top dead center before relatively descending the punch.

Further, the invention is characterized not only by the above-noted features of the invention, but also by, after a workpiece having a known plate thickness is mounted on the die before actual bending and the punch is relatively descended to detect the stroke quantity using the ram position detection means and to detect the displacement quantity of the displacement gauge at this time, further comprising a reference inter-blade distance arithmetic operation section for adding the plate thickness of the workpiece to the relative stroke quantity of the punch and subtracting the displacement quantity of the displacement gauge from the addition result, thereby calculating the reference inter-blade distance.

To attain the above object, the invention is a reference inter-blade distance detector for obtaining a reference inter-blade distance which is a distance between a punch and a die at an arbitrary reference position, characterized by comprising: a displacement gauge provided to be always urged upward in a V-groove of the die, and measuring a distance from an upper surface of the die to a lower surface of a workpiece; ram position detection means for detecting a relative stroke quantity of the punch; and a reference inter-blade distance arithmetic operation section, after a workpiece having a known plate thickness is mounted on the die and the punch is relatively moved to allow the punch to bend the workpiece in cooperation with the die, for adding the known plate thickness to a stroke quantity of the punch at this time and subtracting a displacement quantity of the displacement gauge from the addition result, and thereby detecting the reference inter-blade distance.

To attain the above object, the invention is a bending method for directly detecting a relative stroke value of a punch to a die using a vertically movable displacement gauge provided in the die and protruded from a V-groove of the die, and for controlling a relative stroke of the punch, characterized by: inputting various conditions including workpiece conditions, die conditions and a target bending angle; obtaining a corresponding relative stroke value of the punch based on the input target bending angle; causing the punch to make the relative stroke by the relative stroke value, and bending the workpiece cooperatively by the punch and the die; actually measuring a bending angle of the bent workpiece; and correcting the relative stroke value based on the actually measured bending angle and the target bending angle.

To attain the above object, the invention is a bending apparatus for directly detecting a relative stroke value of a punch to a die using a vertically movable displacement gauge provided in the die and protruded from a V-groove of the die, and for controlling a relative stroke of the punch, characterized by comprising: input means for inputting various conditions including workpiece conditions, die conditions and a target bending angle; stroke value calculation means for obtaining a corresponding relative stroke value of the punch based on the input target bending angle; bending means for causing the punch to make the relative stroke by the relative stroke value, and bending the workpiece cooperatively by the punch and the die; angle measurement means for actually measuring a bending angle of the bent workpiece; and correction means for correcting the relative stroke value based on the actually measured bending angle and the target bending angle.

To attain the above object, the invention is a bending method for directly detecting a relative stroke value of a punch to a die using a vertically movable displacement gauge provided in the die and protruded from a V-groove of the die, and for controlling a relative stroke of the punch, characterized by: inputting various conditions including workpiece conditions, die conditions and a target bending angle; obtaining the relative stroke value of the punch corresponding to the input conditions from data stored in a database in advance or a theoretical expression based on an experiment; causing the punch to make the relative stroke by the relative stroke value, and bending the workpiece cooperatively by the punch and the die; actually measuring a bending angle of the bent workpiece; and if a difference between the actually measured bending angle and the target bending angle is not within a tolerance, correcting the data stored in the database based on the difference; correcting the relative stroke value based on the corrected data; further bending the workpiece based on the corrected relative stroke quantity; and repeating correcting the data and further bending the workpiece until the difference between the actually measured bending angle and the target bending angle falls within the tolerance.

Further, the invention is characterized not only by the above-noted features of the invention, but also in that if the data in the database is to be corrected, the data is corrected by displacing the data by the difference between the actually measured bending angle and the target bending angle.

Further, the invention is characterized not only by the above-noted features of the invention, but also in that if the data in the database is to be corrected, the data is corrected by displacing the data by a quantity proportional to the difference between the actually measured bending angle and the target bending angle.

To attain the above object, the invention is a bending apparatus for directly detecting a relative stroke value of a punch to a die using a vertically movable displacement gauge provided in the die and protruded from a V-groove of the die, and for controlling the relative stroke of the punch, characterized by comprising: input means for inputting various conditions including workpiece conditions, die conditions and a target bending angle; a database storing the relative stroke value of the punch corresponding to the various conditions or an expression for calculating the relative stroke value of the punch corresponding to the various conditions; stroke value calculation means for obtaining the relative stroke value of the punch corresponding to the input conditions from the data stored in the database; a stroke instruction section for causing the punch to make the relative stroke by the relative stroke value; a comparison determination section for actually measuring a bending angle of the bent workpiece, and determining whether or not a difference between the actually measured bending angle and the target bending angle is within a tolerance; and a data correction section for, it the difference between the actually measured bending angle and the target bending angle is not within the tolerance, correcting the data stored in the database based on the difference, and characterized in that the stroke value calculation means corrects the relative stroke value based on the corrected data, and the stroke instruction section causes the punch to make the relative stroke by the corrected relative stroke value, thereby repeatedly correcting the relative stroke value and causing the punch to make a stroke by the stroke instruction section until the difference between the actually measured bending angle and the target bending angle falls within the tolerance.

Further, the invention is characterized not only by the above-noted features of the invention, but also in that the data correction section corrects the data by displacing the data by the difference between the actually measured bending angle and the target bending angle.

Further, the invention is characterized not only by the above-noted features of the invention, but also in that the data correction section corrects the data by displacing the data by a quantity proportional to the difference between the actually measured bending angle and the target bending angle.

To attain the above object, the invention is a bending method for directly detecting a relative stroke value of a punch to a die using a vertically movable displacement gauge provided in the die and protruded from a V-groove of the die, and for controlling a relative stroke of the punch, characterized by: inputting various conditions including workpiece conditions, die conditions and a target bending angle; obtaining the relative stroke value of the punch corresponding to the input target bending angle from a stroke value-to-angle relationship stored in a database in advance; causing the punch to make the relative stroke by the relative stroke value, and bending the workpiece cooperatively by the punch and the die; measuring a bending load for a certain stroke value before a stroke value reaches a target stroke value, comparing the measured bending load with the stroke value-to-angle relationship stored in the database in advance, and correcting the stroke value-to-angle relationship stored in the database; correcting the target stroke value from the corrected stroke value-to-angle relationship; and bending the workpiece using the corrected stroke value-to-angle relationship as a target.

To attain the above object, the invention is a bending apparatus for directly detecting a relative stroke value of a punch to a die using a vertically movable displacement gauge provided in the die and protruded from a V-groove of the die, and for controlling a relative stroke of the punch, characterized by comprising: input means for inputting various conditions including workpiece conditions, die conditions and a target bending angle; a database storing the input various data, a stroke value-to-angle relationship and a stroke value-to-load relationship both obtained in advance; stroke value calculation means for obtaining the relative stroke value of the punch corresponding to the target bending angle from the stroke-value-to-angle relationship stored in the database; a stroke instruction section controlling driving means so as to cause the punch to make the relative stroke for the obtained relative stroke value; load detection means for detecting a bending load at a certain stroke position until a stroke value reaches the target stroke value; and a stroke value-to-angle correction section for correcting the stroke value-to-angle relationship stored in the database based on the bending load detected by the bending load detection means, and characterized in that the stroke value calculation means obtains a new relative stroke value from the stroke value-to-angle relationship corrected by the stroke value-to-angle correction section.

To attain the above object, the invention is a bending method for causing a punch to make a relative stroke based on input bending data including workpiece conditions, die conditions and bending conditions, for directly detecting a relative stroke value of the punch to a die using a vertically movable displacement gauge provided in the die and protruded from a V-groove of the die, and for controlling the relative stroke of the punch, characterized by: measuring a before-bending plate thickness of the workpiece; calculating a spring back quantity of the workpiece based on the measured before-bending plate thickness of the workpiece and the bending data; calculating an insertion angle based on the calculated spring back quantity; calculating the relative stroke quantity of the punch for bending the workpiece for the insertion angle; calculating a radius of curvature of the workpiece right under the punch if the workpiece is bent for the insertion angle; calculating an after-bending plate thickness of the workpiece when the workpiece has been bent, based on the calculated radius of curvature of the workpiece and the before-bending plate thickness of the workpiece; calculating a final stroke value of the punch based on the before-bending plate thickness of the workpiece, the after-bending plate thickness of the workpiece and the insertion angle; and relatively moving the punch to obtain the final stroke value and thereby bending the workpiece while monitoring the stroke using the displacement gauge.

To attain the above object, the invention is a bending apparatus for causing a punch to make a relative stroke based on bending data including workpiece conditions, die conditions and bending conditions input by input means, for directly detecting a relative stroke value of the punch to a die using a vertically movable displacement gauge provided in the die and protruded from a V-groove of the die, and for controlling the relative stroke of the punch, characterized by comprising: plate thickness measurement means for measuring a before-bending plate thickness of the workpiece; spring back quantity arithmetic operation means for calculating a spring back quantity of the workpiece based on the measured before-bending plate thickness of the workpiece and the bending data; insertion angle arithmetic operation means for calculating an insertion angle based on the calculated spring back quantity; stroke arithmetic operation means for calculating the relative stroke quantity of the punch for bending the workpiece for the insertion angle; workpiece radius-of-curvature arithmetic operation means for calculating a radius of curvature of the workpiece right under the punch if the workpiece is bent for the insertion angle; plate thickness arithmetic operation means for calculating an after-bending plate thickness of the workpiece when the workpiece has been bent, based on the calculated radius of curvature of the workpiece and the before-bending plate thickness of the workpiece; final stroke arithmetic operation means for calculating a final stroke value of the punch based on the before-bending plate thickness of the workpiece, the after-bending plate thickness of the workpiece and the insertion angle; and a stroke instruction section for relatively moving the punch based on the final stroke value and bending the workpiece while monitoring the stroke using the displacement gauge.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an explanatory view showing a D-value detection method for a conventional bending apparatus.

FIG. **2** is a cross-sectional view showing a conventionally known displacement gauge for directly measuring a D-value.

FIG. **3** is a front view of a press brake which is a bending apparatus according to the present invention.

FIG. **4** is a side view of the press brake viewed from a direction II shown in FIG. **3**.

FIG. **5** is a cross-sectional view showing a displacement gauge.

FIG. **6** is an explanatory view showing an inter-blade distance.

FIG. **7** is a block diagram showing the configuration of a controller which serves as a plate thickness detector in a bending machine according to the present invention.

FIG. **8** is a cross-sectional view showing the calibration of the displacement gauge.

FIG. **9** is a cross-sectional view of an upward convex workpiece.

FIG. **10** is a cross-sectional view of a downward convex workpiece.

FIG. **11** is a graph showing the relationship between the stroke of a punch and the stroke of a displacement gauge.

FIG. **12** is a flow chart showing a plate thickness detection method for the bending machine according to the present invention.

FIG. **13** is an explanatory view for a reference inter-blade distance.

FIG. **14** is a flow chart showing calibration bending.

FIG. **15** is a flow chart showing product bending.

FIG. **16** is a block diagram showing the configuration of a controller in the second embodiment.

FIG. **17** is a flow chart showing the steps of a bending method according to the second embodiment.

FIG. **18** is a graph showing the relationship between angle and inter-blade distance.

FIG. **19** is a cross-sectional view showing a state of bending.

FIG. **20** is a graph showing that the relationship between the angle and the inter-blade distance is corrected if it is assumed that Young's modulus has no change.

FIG. **21** is a graph showing that the relationship between the angle and the inter-blade distance is corrected if it is assumed that an n-value has no change.

FIG. **22** is a block diagram showing the configuration of a controller according to the third embodiment.

FIG. **23** is a flow chart showing the steps of a bending method according to the third embodiment.

FIG. **24** is a graph showing the relationship between angle and inter-blade distance.

FIG. **25** is a graph showing the relationship between stroke and bending load.

FIG. **26** is a block diagram showing the configuration of a controller according to the fourth embodiment.

FIG. **27** is a flow chart showing a bending method according to the third embodiment.

FIG. **28** is a flow chart for reflecting the decrease of the plate thickness of a work by bending on stroke control.

FIG. **29** is an explanatory view showing the plate thickness of the workpiece before bending.

FIG. **30** is an explanatory view showing the plate thickness of the workpiece after bending.

FIG. **31** is an explanatory view showing the relationship between the radius of curvature of the workpiece and the plate thickness thereof after bending.

BEST MODES FOR CARRYING OUT THE INVENTION

The embodiments of the present invention will be described hereinafter in detail with reference to the drawings.

FIGS. **1** and **2** show a press brake **1** which serves as a bending apparatus according to the present invention. Since the press brake **1** is already well known, it will be described only schematically.

The press brake **1** has left and right side plates **3**L and **3**R each of which has a gap G in a central portion on entire surfaces and is generally C shaped, and an upper table **5**U which serves as a ram is provided to be vertically movable on the front surface of the upper portion of each of the side plates **3**L and **3**R. This upper table **5**U has a punch P which is attached to the lower end of the table **5**U through an intermediate plate **7** in an exchangeable fashion and is vertically moved by a ram driving means **9** including a hydraulic cylinder, a motor, a ball spring and so on provided on the upper portion of each of the side plates **3**L and **3**R. A ram position detection means **11** such as an encoder or linear scale for detecting the upper and lower positions of the upper table **5**U is provided. Further, a bending load detector which serves as a bending load detection means is attached to the ram driving means **9**.

On the other hand, a lower table **5**L is provided on the front surface of the lower portion of each of the side plates **3**L and **3**R, and a die D is attached to the upper end of this lower table **5**L through a die holder **13** in an exchangeable fashion. A V-groove **15** (see FIGS. **5** and **6**) for bending a workpiece W is provided on the upper portion of the die D in the longitudinal direction of the die D. Further, a controller **17** controlling the ram driving means **9** and the like, to be described later, is provided in the vicinity of the press brake **1**.

With the above-stated configuration, the punch P is descended by the ram driving means **9** toward the workpiece W which is positioned between the punch and the die D, the ram position detection means **11** detects the upper and lower positions of the upper table **5** which serves as a ram, the controller **17** controls the position of the punch P, and the punch P and the die D cooperatively bend the workpiece W.

Referring also to FIG. **5**, a plurality of displacement gauges **19** are provided in the die D in the longitudinal direction of the die D. Each of the displacement gauges **19** is provided with a detection pin **23** which is always urged upward by a spring **21** and which is protruded vertically movably from the V groove **15** of the die D, and with a linear scale **25** for detecting the upper and lower positions of the detection pin **23**.

Accordingly, the workpiece W which is bent by the punch P presses the detection pin **23** down, the linear scale **25** detects the upper and lower positions of the detection pin **23** at the time of being pressed, and, as shown in FIG. **6**, the distance DSt between the upper end portion of the detection pin **23** and the upper surface of the die D is detected.

A plate thickness detection method, a plate thickness detector, a reference inter-blade distance detection method and a reference inter-blade distance detector as the first embodiment of the present invention will first be described with reference to FIGS. **7** to **15**.

FIG. **7** shows a block diagram of the controller **17**. This controller **17** includes a CPU **27** or a central processing unit, to which an input means **29** such as a keyboard for inputting various data and an output means **31** such as a CRT for displaying the various data are connected. Further, the ram position detection means **11** and the displacement gauges **19** are connected to the CPU **27** so that a detection signal can be transmitted to the CPU **27**.

Furthermore, a memory **33** storing the various data and a plate thickness arithmetic operation section **35** which calculates the plate thickness of the workpiece W mounted on the die D from the stroke quantity of the punch P detected by the ram position detection means **11** and the movement quantities of the displacement gauges **19** detected by the displacement gauges **19** as will be described later, are connected to the CPU **27**. As will be described later, a reference inter-blade distance arithmetic operation section **37** which calculates a reference inter-blade distance which is the inter-blade distance between the punch P and the die D as a reference to be employed for the arithmetic operation of the plat thickness, is also connected to the CPU **27**.

A method for measuring the plate thickness T of the workpiece W will next be described.

First, a method for measuring the plate thickness of the workpiece W by descending the ram from a top dead center (i.e., the top dead center of the punch P) will be described. Referring to FIG. **3**, in the press brake **1**, an open height is denoted by H, the height of an intermediate plate **7** is denoted by HB, the height of the punch P is denoted by HP, the height of the die D is denoted by HD and the height of the die holder **13** is denoted by HC. Accordingly, these are known values in the press brake **1** and so is well known the reference inter-blade distance=H−HB−HP−HC−HD. Further, the stroke of the punch P from the top dead center in a downward direction is denote by PSt as shown in FIG. **3**, and that of the detection pin **23** from the upper surface of the die D in the downward direction is denoted by DSt as shown in FIG. **6**.

Referring to FIG. **8**, the displacement gauge **19** measures the stroke DSt downward with the upper surface position of the die D set as an origin. Using a calibration tool **39** having a polished lower surface, this displacement gauge **19** obtains the origin in advance. Therefore, as shown in FIG. **9**, if the workpiece W is warped to be convex upward, the sign of the initial value of DSt is minus. As shown in FIG. **10**, if the workpiece W is warped to be convex downward, the sign of the initial value of DSt is plus.

FIG. **11** shows the relationship between the stroke PSt of the punch P and the stroke DSt of the detection pin **23** relative to time. In FIG. **11**, a point **P1** denotes the contact point between the punch P and the workpiece W and a point **P2** denotes a predetermined point after bending starts. In addition, a stroke PSt**1** denotes the stroke value of the punch P relative to the point **P1**, a stroke PSt**2** denotes the stroke value of the punch P relative to the point **P2**, a stroke DSt**1** (=0) denotes the stroke value of the detection pin **23** relative to the point **P1** and a stroke DSt**2** denotes the stroke value of the detection pin **23** relative to the point **P2**.

Referring to FIG. **12**, if the plate thickness detection starts (in a step SS), the values of the open height H, the height HB of the intermediate plate **7**, the height HP of the punch P, the height HD of the die D and the height HC of the die holder **13** are input (in a step S**1**). If these values are already input and stored in the memory **33**, they are invoked.

As already stated above, using the calibration tool **39** having a polished lower surface, the displacement gauge **19** is subjected to calibration (in a step S**2**). Namely, the upper surface position of the die D is set at DSt=0.

The upper table **5**U, as a ram, is descended by the ram driving means **9** to start bending (in a step S**3**), it is determined whether or not the punch P contacts with the workpiece W (or whether or not the punch P contacts with the workpiece W and then bent by a certain quantity as indicated by the point P2 shown in FIG. **11**) (in a step S**4**), and the upper table **5**U is descended back to the step S**3**.

In the step S**4**, if it is determined that the punch P contacts with the workpiece W, the stroke value PSt of the punch P and the stroke value DSt of the detection piece **23** at the time of the determination are obtained, and the plate thickness T of the workpiece W is obtained from T=H−(HB+HP+HD+HC+PSt)+DSt (in a step S**5**, see FIG. **3**), thereby completing the measurement of the plate thickness (in a step SE).

If the determination is made with reference to the contact between the punch P and the workpiece W, the PSt**1** and

DSt1 (=0) are employed as PSt and DSt, respectively. If the determination is made with reference to the progress of bending by a certain degree, the PSt2 and DSt2 are employed as PSt and DSt, respectively. However, if the bending progresses so largely, the plate thickness is decreased by the bending. It is, therefore, desirable to detect the plate thickness so as not to excessively bend the workpiece W.

Since the plate thickness T of the workpiece W is calculated using the open height H, it is desirable that the frames such as the side plates **3**L and **3**R of the press brake **1** are less thermally deformed so as not to change the open height H. That is, a press brake of such a type as to drive a hydraulic cylinder by a bidirectional pump as the ram driving means **9** (hybrid press brake) is suitable.

Next, a method for measuring the plate thickness T of the workpiece W without reference to the top dead center of the ram as described above will be described. In this method, a reference inter-blade distance a is set as a reference.

Referring to FIG. **13**, using a workpiece W the plate thickness T0 of which is known, the reference inter-blade distance a is obtained from a=PSt+T0−DSt and stored in the memory **33**. Thereafter, the punch P is descended toward the workpiece W for which the plate thickness T is to be measured and the plate thickness T is obtained from T=a−(PSt−DSt).

Referring to FIG. **14**, if calibration bending starts (in a step SS), the displacement gauge **19** is subjected to calibration with reference to the upper surface of the die D as already described (in a step S**6**).

Bending starts to the workpiece W having the known plate thickness T0 (in a step S**7**) and it is determined whether or not the punch P contacts with the workpiece W (in a step S**8**). If the punch P does not contact with the workpiece W, the processing returns to the step S**7**, in which the punch P is descended. If it is determined that the punch P contacts with the workpiece W, then the stroke value PSt of the punch P and the stroke value DSt of the displacement gauge **19** at the time of the contact are obtained, the reference inter-blade distance a is calculated from a=PSt+T0−DSt (in a step S**9**) and the calibration bending is thereby ended (in a step SE).

Referring next to FIG. **15**, if product bending starts (in a step SS), the punch P is descended toward the workpiece W the plate thickness T of which is unknown to conduct bending (in a step S**10**). It is determined whether or not the punch P contacts with the workpiece W (in a step S**11**) and the punch P is descended until it contacts with the workpiece W. If the punch P contacts with the workpiece W, then the stroke PSt of the punch P and the stroke DSt of the detection pin **23** of the displacement gauge **19** at the time of the contact are obtained, the plate thickness T is obtained from T=a−(PSt−DSt) (in a step S**12**) and the product bending is ended (in a step SE).

If the plate thickness T is obtained as stated above, the plate thickness T can be measured without giving consideration to the influence of the thermal deformations of the frames of the press brake **1** as described above. Further, since the ram top dead center is not set as a reference, it is possible to cause the punch P to make a stroke from an arbitrary position and to measure the plate thickness T.

The above-stated results evidence that the plate thickness T can be detected if the stroke PSt of the punch P and the stroke DSt of the detection pin **23** of the displacement gauge **19** can be detected at the same time after bending starts. Therefore, it is possible to measure the plate thickness T at a bending start point, a point at which bending progresses by a certain degree (or a point at which a bending quantity exceeds a certain threshold) or the like.

Furthermore, as shown in FIGS. **9** and **10**, even if the workpiece W is warped, it is possible to accurately measure the plate thickness T.

Referring to FIGS. **16** to **21**, a bending method and a bending apparatus according to the second embodiment of the present invention will next be described.

Referring first to FIG. **16**, a controller **41** includes a CPU **27** or a central processing unit, to which an input means **29** such as a keyboard for inputting various data and an output means **31** such as a CRT for displaying the various data are connected. In addition, a database **43** which will be described later, a data correction section **45** correcting the database **43** by a method which will be described later, a comparison determination section **47** comparing the measured bending angle of the bent workpiece W with a target angle, and a stroke instruction section **49** controlling a vertical cylinder **50** and thereby controlling the stroke of the punch P, are connected to the CPU **27**. Further, a displacement gauge **19** is connected so that a detection signal can be transmitted.

Referring to FIGS. **17** to **21**, the bending method according to the second embodiment will next be described.

When a processing starts (in a step SS), bending conditions such as a bending angle, die conditions including a die groove angle DA, a die V width V, a die shoulder are DR and a punch tip end are PR, material conditions including an n-power law hardening exponent, Young's modulus E and a plastic coefficient F, and the plate thickness are input (in a step S**21**).

Using a graph showing the relationship between the bending angle and the inter-blade distance stored in the database **43** as shown in FIG. **18** or a calculation expression, an inter-blade distance ST1 at an insertion angle to obtain a desired bending angle (90 degrees in this case) is obtained (in a step S**22**). In other words, the graph or calculation expression showing the relationship between the bending angle and the inter-blade distance ST1 shows a finishing angle which is an actual bending angle and an insertion angle in consideration of a spring back quantity calculated from material conditions for each material in advance, it is possible to obtain the insertion angle.

Thereafter, bending starts (in a step S**23**). As shown in FIG. **19**, while observing the displacement gauge **19**, the inter-blade distance is driven to the target blade distance ST1 obtained in the step S**22** (in a step S**24**). If the distance reaches the target inter-blade distance ST1, the workpiece W is unloaded (in a step S**25**).

The punch P is separated from the die D to take out the workpiece W (in a step S**26**), and a finishing angle θ' is measured (in a step S**27**). It is then determined whether or not the finishing angle is within a tolerance (in a step S**28**). If it is determined that the finishing angle is within a tolerance, the inter-blade distance is recorded as a final inter-blade distance ST for the material conditions and bending conditions at this time (in a step S**29**) and the bending is ended (in a step SE).

On the other hand, if it is determined that the finishing angle is not within the tolerance, the relationship between the bending angle θ and the inter-blade distance ST1 is corrected to obtain a corrected inter-blade distance ST2 (in a step S**30**). As this correction method, a method for correcting the distance while assuming that Young's modulus E has no change and a method for correcting the distance while assuming that the n-value has no change may be employed.

Description will now be given while taking a target bending angle of 90 degrees as an example.

First, referring to FIG. **20**, in the correction method on the assumption that the Young's modulus E, i.e., spring back has no change, a finishing angle line is corrected so as to pass the intersection **P1** between the inter-blade distance ST1 relative to the target bending angle of 90 degrees before correction and the actual finishing angle θ'. Since the angle difference between the insertion angle and the finishing angle has no change between before-correction and after-correction, an insertion angle line and a finishing angle line are displaced by a quantity proportional to the difference θ'−90 between the target bending angle of 90 degrees and the measured finishing angle θ' at the center of one point (indicated by broken lines in FIG. **20**, respectively). As a result, the inter-blade distance ST2 after the correction is obtained from the intersection **P2** between the target bending angle of 90 degrees and the finishing angle.

As other methods for displacing the insertion angle line and the finishing angle line, there are a method for offsetting a displacement quantity in parallel, a method for re-calculating an inter-blade distance at each angle using the reciprocal of a material constant and the like.

In the correction method on the assumption that the n-value, i.e., a plastic range has no change, the insertion angle does not change. Therefore, as shown in FIG. **21**, the finishing angle line is displaced by the difference θ'−90 between the target bending angle of 90 degrees and the measured finishing angle θ' (indicated by a broken line in FIG. **21**).

As methods for displacing the finishing angle line, there are a method for offsetting displacement quantities in parallel, a method for re-calculating an inter-blade distance at each angle using the reciprocal of the material constant besides a method for displacing the line at the center of one point, as in the case of the correction method on the assumption that the Young's modulus E has no change.

Next, the workpiece W which has been bent is re-set and a drive-in processing starts (in a step **S31**), followed by a step **S24** to repeat the steps after the step **S24**. Here, if the finishing angle θ' measured previously is not more than 90 degrees, the workpiece W is already bent excessively. Therefore, a new workpiece W is used to start over bending without using the previously bent workpiece W.

From the above-stated results, the bending angle obtained by the first bending is measured and the graph or calculation expression showing the relationship between the bending angle and the inter-blade distance ST is corrected based on the difference between the measured angle and the target angle, so that it is possible to obtain an accurate inter-blade distance ST for the bending angle. It is thereby possible to bend workpieces W of the same material at accurate angle by once bending.

Next, the third embodiment of the present invention will be described with reference to FIGS. **22** to **25**.

Referring first to FIG. **22**, a controller **51** includes a CPU **27** or a central processing unit, to which an input means **29** such as a keyboard for inputting various data and an output means **31** such as a CRT for displaying the various data are connected. Further, a displacement gauge **19** already described above and a bending load detector **57** which is a bending load detection means are connected to the CPU **27** so that a detection signal can be transmitted.

Furthermore, a database **43** storing the various data input from the input means **29**, the relationship between stroke value and angle and that between stroke value and load, a stroke value-angle correction means **53** for correcting the stroke value-angle relationship stored in the database **43** based on a measured stroke value and a measure bending load while bending a workpiece using the displacement gauge **19** and the bending load detector **57**, a stroke value calculation means **55** for calculating a new target stroke value from the stroke value-angle relationship corrected by this stroke value-angle correction means **53**, and a stroke instruction section **49** controlling a vertical cylinder **50** and thereby control the stroke of a punch P, are connected to the CPU **27**.

A bending method according to the third embodiment will next be described with reference to FIGS. **23** to **25**.

When a processing starts (in a step SS), bending conditions such as a target bending angle θ**0**, die conditions including a die groove angle DA, a die V width V, a die shoulder are DR and a punch tip end are PR, material conditions including an n-power law hardening exponent, Young's modulus E and a plastic coefficient F and a plate thickness t and the like are input from the input means **29** (in a step **S41**).

Next, the stroke value calculation means **55** calculates the target stroke value ST0 of the punch P for a target bending angle θ**0** from the stroke value-bending angle θ relationship stored in the database **43** (in a step **S42**). Namely, as shown in FIG. **24**, the target stroke value ST0 for the inputted target bending angle θ**0** (e.g., 90 degrees) is calculated from the stroke value-bending angle relationship θ obtained by an experiment or the like in advance and stored in the database **43**.

Bending starts for the target stroke value ST0 (in a step **S43**), the actual plate thickness of the workpiece W is measured by an external plate thickness measurement means such as a caliper (in a step **S44**). Alternatively, the actual plate thickness may be measured before the bending start and input as a bending condition in advance.

As already shown in FIG. **6**, the stroke value ST is measured using the displacement gauge **19** while the punch P is relatively descended, a load F at this time is detected by the bending load detector **27**, and bending—bending loads **F1**, **F2** and **F3** for a plurality of (e. g., two to four, three or one) arbitrary stroke values ST1, ST2 and ST3 are detected until the stroke value ST reaches a target stroke value ST0 as shown in FIG. **25** (in a step **S45**).

As the bending load detector **57**, a hydraulic sensor may be employed in a hydraulic press brake **1**. The bending load can be measured from the torque of a motor in a press brake using a ball spring. Alternatively, the bending load may be detected by attaching a gauge to each frame.

Next, the stroke-angle correction section **53** obtains a stroke value correction quantity a based on the three couples of stroke value and bending load value (ST1, **F1**), (ST2, **F2**) and (ST3, **F3**) obtained in the step **S45** (in a step **S46**). Here, the correction quantity a is a function of the actual plate thickness, bending loads at certain stroke positions (ST1, **F1**), (ST2, **F2**) and (ST3, **F3**), die conditions, a material constant, the target stroke value ST0, the target bending angle θ**0** and the like. That is, the correction quantity a is given by a=f(actual plate thickness, bending loads at certain stroke positions (ST1, **F1**), (ST2, **F2**) and (ST3, **F3**), die conditions, material constant, target stroke value ST0, target bending angle θ**0**).

The stroke-angle correction section **53** corrects the target stroke value ST0 using the correction quantity a as described above, thereby obtaining (corrected target stroke value ST0)=(previous target stroke value ST0)−a (in a step **S47**).

The stroke instruction section **49** causes the punch P to make a stroke relative to the corrected target value ST0 and if it is determined that the target stroke value reaches the corrected target value ST0 (in a step S**48**), the bending is ended (in a step SE).

As can be seen from these results, a bending load for a certain stroke value is measured until the stroke value reaches a stroke value for the tentative target angle obtained from the stroke value-angle relationship stored in the database **43**, this measured value is compared with the stroke value-load relationship stored in the database **43** in advance to thereby correct the stroke value-angle relationship. It is, therefore, possible to calculate a true stroke value for a target bending angle. It is possible to carry out bending with high accuracy, accordingly.

Finally, the fourth embodiment of the present invention will be described with reference to FIGS. **26** to **31**.

First, referring to FIG. **26**, a controller **61** includes a CPU **27** or a central processing unit, to which an input means **29** such as a keyboard for inputting various data and an output means **31** such as a CRT for displaying the various data are connected. A displacement gauge **19** is also connected to the CPU **27** so that a detection signal can be transmitted.

Further, a spring back quantity arithmetic operation means **63** for calculating a spring back quantity $\Delta\theta$ based on the inputted bending conditions, an insertion angle arithmetic operation means **65** for calculating an insertion angle θ**1** based on the spring back quantity $\Delta\theta$, a workpiece radius-of-curvature arithmetic operation means **67** for calculating the radius of curvature ρ of a workpiece W right under a punch P based on the insertion angle θ**1**, a stroke arithmetic operation means **69** for obtaining a target insertion angle θ**1** based on a before-bending plate thickness T1 which is a true plate thickness before bending starts, a plate thickness arithmetic operation means **71** for calculating an after-bending plate thickness T2 at bending end time t1 from the calculated radius of curvature ρ of the workpiece W and the before-bending plate thickness T1, a final stroke arithmetic operation means **73** for calculating a final stroke (bottom position) from the before-bending plate thickness T1 and the after-bending plate thickness T2, are connected to the CPU **27**. It is noted that a stroke instruction section **49** instructing a vertical cylinder **50** to elevate the punch is also connected to the CPU **27**.

A bending method according to the fourth embodiment will next be described with reference to FIGS. **27** to **31**.

When a processing starts (in a step SS), bending conditions such as a target bending angle θ, die conditions including a die groove angle DA, a die V width V, a die shoulder are DR and a punch tip end are PR, material conditions including an n-power law hardening exponent, Young's modulus E and a plastic coefficient are input by the input means **29** (in a step S**51**).

The plate thickness measurement means **75** such as caliper measures the plate thickness of the workpiece W and the before-ending plate thickness T1 (see FIG. **29**) which is a true plate thickness is input from the input means **29** (in a step S**52**) and the plate thickness arithmetic operation means **71** calculates a bending quantity at the before-bending plate thickness T1, thereby obtaining a stroke value ST and the after-bending plate thickness T2 of the workpiece W after bending right under the punch P (in a step S**53**).

Referring to FIG. **30**, the final stroke arithmetic operation means **73** calculates a target bottom position ST0 on the lower surface of the workpiece W from ST=ST−(T1−T2) (in a step S**54**) and bending is conducted down to the target bottom position ST0 (in a step S**55**).

Referring to FIG. **28**, in the above-stated bending, the spring back quantity arithmetic operation means **63** calculates the spring back quantity $\Delta\theta$ (in a step S**57**) from the bending conditions such as the bending angle θ, the actual plate thickness T1 of the workpiece W, a bending length B, a friction coefficient μ, the die groove angle DA, the die V width V, the die shoulder are DR, the punch tip end are PR, the material conditions including the n-power law hardening exponent, the Young's modulus E and the plastic coefficient F input in the steps S**51** and S**52** (in a step S**56**). That is, the spring back quantity $\Delta\theta$ is calculated from ?θ=f**1** (θ**1**, T1, B, μ, DA, V, DR, PR, n, E, F).

Next, the insertion angle arithmetic operation section **65** subtracts the spring back quantity ?θ from the target bending angle θ and thereby calculates the insertion angle θ**1**. That is, the insertion angle θ**1** is calculated from θ**1**=θ−$\Delta\theta$ (in a step S**58**).

The workpiece radius-of-curvature arithmetic operation means **67** calculates the radius of curvature ρ of the workpiece W right under the punch P at the time of bending the workpiece W at the calculated insertion angle θ**1** from ρ=f**3** (θ**1**, T1, B, μ, DA, V, DR, PR, n, F) (in a step S**59**). Referring then to FIG. **31**, the plate thickness arithmetic operation means **71** calculates the after-bending plate thickness T2 of the workpiece right under the punch P after the workpiece W is bent at the insertion angle θ**1** from T2=f**4** (ρ, T1) (in a step S**60**).

The stroke arithmetic operation means **69** calculates a punch stroke St which becomes a tentative target bottom position for the target insertion angle θ**1** if the plate thickness of the workpiece W being bent is the before-bending plate thickness T1 from St=f**2**(θ**1**, T1, B, μ, DA, V, DR, PR, n, F) (in a step S**61**).

Since the plate thickness of the workpiece W decreases and the bottom position of the actual workpiece W is displaced during the bending, the tentative target bottom position St previously obtained is shifted upward by as much as a decrease in plate thickness (T1−T2) to thereby correct the bottom position of the punch P (in a step S**62**). Namely, since the punch stroke STB at a final bottom position is obtained from STB=St−(T1−T2), the stroke instruction section **49** controls the stroke of the punch P using this punch stroke STB to thereby carry out the bending (in a step S**63**).

Referring back to FIG. **27**, the bending is ended (in a step SE).

As can be seen from these results, the final stroke quantity of the punch P is calculated in light of a decrease in the plate thickness of the workpiece W following the bending and the bending is carried out based on this stroke value, so that it is possible to carry out the bending with high accuracy.

The present invention is not limited to the embodiments stated above and can be executed in other modes. That is, in the above-stated embodiments, the press brake **1** in which the punch P is raised and descended to bend the workpiece has been described. The present invention is also applicable to a press brake of a die D elevation type.

INDUSTRIAL APPLICABILITY

According to the present invention, it is possible to accurately detect the actual plate thickness of a workpiece while bending the workpiece. Even if, in particular, the workpiece is thin or warped, the plate thickness of the workpiece can be accurately detected.

Further, according to the present invention, it is possible to accurately calculate the relative stroke value of a punch for a target bending angle and to carry out bending with high accuracy.

What is claimed is:

1. A plate thickness detection method for a bending machine that bends a workpiece mounted on an upper surface of a die, using a punch and the die cooperatively, the method comprising:

relatively moving a punch from a reference inter-blade distance spaced from the die;

providing, in a V-groove of the die, a displacement gauge that detects a displacement quantity, the displacement gauge being urged upward and measuring a distance to a lower surface of a workpiece;

detecting a relative stroke quantity of the punch using a ram position detector, one of when the displacement gauge initially detects a change in the displacement quantity and at a predetermined point after the change in the displacement quantity is detected;

detecting the displacement quantity when the relative stroke quantity is detected; and

determining a plate thickness of the workpiece by subtracting the detected relative stroke quantity from the reference inter-blade distance and adding the displacement quantity of the displacement gauge.

2. The plate thickness detection method according to claim 1, wherein the reference inter-blade distance is a distance between the punch and the die at a top dead center before relatively moving the punch.

3. The plate thickness detection method according to claim 1, wherein the reference inter-blade distance is calculated by mounting a workpiece having a known plate thickness on the die before actual bending, relatively moving the punch to detect the stroke quantity using the ram position detector, detecting the displacement quantity of the displacement gauge when the stroke quantity is detected, and determining the reference inter-blade distance by adding the known plate thickness of the workpiece to the relative stroke quantity of the punch and subtracting the displacement quantity of the displacement gauge.

4. A reference inter-blade distance detection method for obtaining a reference inter-blade distance between a punch and a die at an arbitrary reference position, comprising:

mounting a workpiece having a known plate thickness on the die;

providing a displacement gauge, that gauges a distance from an upper surface of the die to a lower surface of the workpiece, in the die;

relatively moving the punch to bend the workpiece cooperatively with the die; and

determining the reference inter-blade distance by adding the known plate thickness to a stroke quantity of the punch and subtracting a displacement quantity of the displacement gauge.

5. A plate thickness detector for a bending machine that bends a workpiece mounted on an upper surface of a die, cooperatively using a punch and the die initially separated by a reference inter-blade distance, the detector comprising:

a displacement gauge provided in a V-groove of the die, the displacement gauge being urged upward and measuring a distance from the upper surface of the die to a lower surface of the workpiece;

a ram position detector that detects a relative stroke quantity of the punch; and

a plate thickness calculator that calculates a plate thickness of the workpiece by subtracting the detected relative stroke quantity from the reference inter-blade distance and adding a displacement quantity that is measured by the displacement gauge when the relative stroke quantity is detected, the reference inter-blade distance being one of input and stored in a storage,

wherein the ram position detector detects the relative stroke quantity of the punch, one of when the displacement gauge initially detects a change in the displacement quantity and at a predetermined point after the change in the displacement quantity is detected.

6. The plate thickness detector for a bending machine according to claim 5, wherein the reference inter-blade distance is a distance between the punch and the die at a top dead center before relative movement of the punch.

7. The plate thickness detector for a bending machine according to claim 5, further comprising:

a reference inter-blade distance calculator that calculates a reference inter-blade distance after a workpiece, having a known plate thickness, is mounted on the die before actual bending, and after the punch is relatively moved to detect the relative stroke quantity using the ram position detector and to detect the displacement quantity of the displacement gauge, the reference inter-blade distance calculator calculating the reference inter-blade distance by adding the known plate thickness of the workpiece to the relative stroke quantity of the punch and subtracting the displacement quantity of the displacement gauge.

8. A reference inter-blade distance detector for obtaining a reference inter-blade distance between a punch and a die at an arbitrary reference position, comprising:

a displacement gauge provided in a V-groove of the die, the displacement gauge being urged upward and measuring a distance to a lower surface of a workpiece;

a ram position detector that detects a relative stroke quantity of the punch; and

a reference inter-blade distance calculator that calculates the reference inter-blade distance, after a workpiece having a known plate thickness is mounted on the die and the punch is relatively moved to bend the workpiece in cooperation with the die, the reference inter-blade distance being calculated by adding the known plate thickness to a stroke quantity of the punch and subtracting a displacement quantity of the displacement gauge.

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